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External effects in the utilisation of renewable energy

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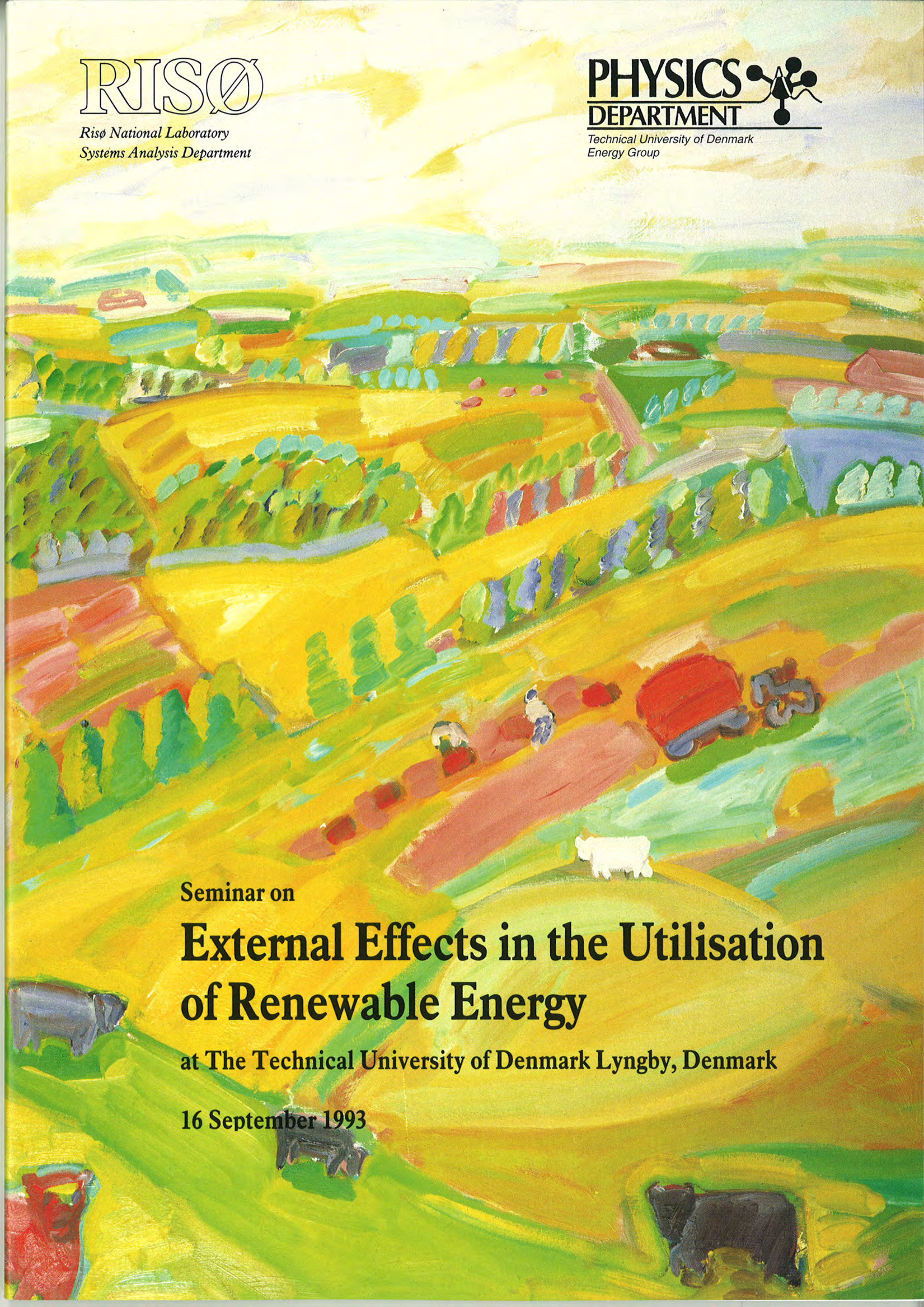

Seminar on

External Effects in the Utilisation of Renewable Energy

at The Technical University of Denmark Lyngby, Denmark

16 September 1993

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Contents

Preface

This report contains papers presented at a seminar concerning external effects in the utilization of renewable energy as compared to traditional energy systems.

The seminar was held at The Technical University of Denmark 16 September 1993 in conjunction with a project concerning external effects in the utilisation of renewable energy financed by the Danish Energy Agency.

The purpose of the seminar was to give an introduction to projects on externalities in Europe in order to create input to the methodology for the Danish project.

The seminar was organised by the project group consisting of:

Henrik Meyer,	The Technical University of Denmark
Niels I. Meyer,	The Technical University of Denmark
Poul Erik Morthorst,	Risø National Laboratory (project manager)
Per S. Nielsen,	The Technical University of Denmark
Lotte Schleisner,	Risø National Laboratory

Introduction

The concept of sustainable development was brought to the attention of the world by the socalled Brundtland-report in 1987. One of the key factors in this connection is the energy sector. Sufficient energy supply is a necessary condition for the desired development in the world, but the energy sector is at the same time one of the major threats to environment. In order to resolve this dilemma and to create a sustainable energy development, radical changes are needed in the energy sector. It is now generally recognized that two elements in the strategy for a sustainable energy development are energy efficiency and renewable energy sources.

Unfortunately there are a number of barriers for the necessary changes in the energy sector. One of them is that externalities can constitute an essential part of the total costs of energy production with large variations between different energy systems. If these external costs to society are not included in the market price, many energy investments may be based on the wrong assumptions.

In order to reduce this barrier, the Danish Council for Renewable Energy has initiated a project to compare externalities from different energy systems based on renewables and fossil fuels. Evaluation of these externalities has a special importance in relation to decisions on environmental charges as a mean for steering the development in the energy sector. In this connection, it is often desired to monetarize the externalities. This is not always possible, however, due to lack of detailed data or because the externality is of a more qualitative type, e.g. degradation of natural beauty or bird diversity. Although externalities have been recognized in traditional economics for a long time, data uncertainties and qualitative valuation pose some difficult methodological problems.

On this background it was decided to organize a one-day international seminar during the starting period of the Danish externality project. The goal was to compare different methodologies and to evaluate their relevance for the Danish project.

The seminar took place in September 1993 and included both theoretical and empirical experiences. The discussion included comments and proposals in relation to the Danish project description. The present proceedings contains the papers presented together with a summary of the discussion.

Seminar on

External Effects in the Utilisation of Renewable Energy

16 September 1993

The Technical University of Denmark
DTH, Main Building, Aud. 1
Lyngby

Programme

9^{30} - 9^{45}	Niels I. Meyer, Technical University of Denmark **Welcome and short presentation**
9^{45} - 10^{45}	Olvar Bergland, Norwegian Agricultural University, Norway **Externalities in economic theory and literature**
10^{45} - 11^{15}	Coffee
11^{15} - 12^{15}	Olav Hohmeyer, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Germany **Renewables and the full costs of energy**
12^{30} - 13^{30}	Lunch
13^{30} - 14^{30}	Knut Alfsen, Central Bureau of Statistics, Norway **Secondary benefits of reduced fossil fuel combustion**
14^{30} - 15^{00}	Coffee
15^{00} - 15^{30}	Poul Erik Morthorst, Risø National Laboratory, Denmark **Presentation of the Danish project *External effects in the utilisation of renewable energy***
15^{30} - 16^{30}	**Comments from the invited speakers** **General discussion of the Danish project**
16^{30} - 16^{45}	Niels I. Meyer, Technical University of Denmark **Concluding remarks**

Externalities in economic theory and literature

Olvar Bergland

Department of Economic and Social Sciences
Agricultural University of Norway
and
Center for Research in Economic and Business Administration (SNF - Oslo)
Norway

The paper was prepared for this seminar.

The paper was presented at the seminar by Olvar Bergland.

Externalities in Economic Theory and Literature*

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Agricultural University of Norway
and
Center for Research in Economics and Business Administration (SNF – Oslo)

10 September, 1993

Contents

*Lecture prepared for the seminar on *External Effects in the Utilization of Renewable Energy* held 16 September, 1993, at the Technical University of Denmark, Lyngby.

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1 Introduction

The topic of this lecture is the economics of externalities. Externalities is generally viewed as occurring whenever the welfare of some individual is affected not only by the activities under his or her control but also by activities under control by someone else.

The subject matter of externalities is a large one which could easily be the topic of several university classes. In this review I will highlight some of the key results and controversies in the field. Although I will be fairly general in my presentation, I will keep an eye on the topic of this conference — externalities associated with production of energy.

The outline of this talk is briefly:

- definition of the concept of externalities
- the Pigouvian and Coasian approaches
- optimal level of externalities
- cost-benefit analysis and externalities
- pricing the environment

Let me state at the outset that my point of departure is mainstream microeconomic theory. My methodological position is that methodological individualism is a very useful approach for analyzing economic behavior in society, although this is not the only approach, nor is it always the best approach to studying human behavior and societies. Neoclassical microeconomic theory with its modern tools and focus on limited, costly and asymmetric information represents a consistent and well developed logical framework for analyzing externalities in a useful and relevant fashion[1]. It is the most relevant parts of this framework I will sketch here and apply it to the externality problem.

The concept of externalities can be traced back to the earliest writings in economics, including Adam Smith's *Wealth of Nations*, published in 1776, although a more detailed analysis had to wait until the marginalist revolution came a century later.

The analysis of externalities can be said to have started in earnest with Sidgwick (1901), Marshall (1922), and in particular Pigou (1924). The paper by Bator (1958) has been extremely influential in forming the externality concept and the policy response to any perceived externalities.

In terms of review papers, see the papers by Mishan (1971), Furubotn and Pejovich (1972), and Heller and Starrett (1976). Important papers in the development of the field include Buchanan and Stubblebine (1962), Dolbear (1967), Ayres (1969), Wheaton (1972), Diamond and Mirrlees (1973), and Dahlman (1979). Unfortunately there is a lack of more recent review papers, but the book by Cornes and Sandler (1986) summarizes the field as of the mid-eighties.

A somewhat different approach to the externality issues is given by Kapp (1950). The institutionalists critique of the neoclassical approach to externalities is summarized in Schmid (1987) and Bromley (1991). The radical critique of the whole mainstream neoclassical approach to externalities is forcefully put forth by Hunt (1980). An alternative radical critique is provided by Hahnel and Albert (1990).

[1] The modern approach to microeconomic theory is well described in the text by Kreps (1990).

2 Defining Externalities

Let me start with considering the following definition of externality originally proposed by James Meade:[2]

> An external economy (diseconomy) is an event which confers an appreciable benefit (inflicts an appreciable damage) on some person or persons who were not fully consenting parties in reaching the decision or decisions which led directly or indirectly to the event in question.

Externality is thus a very broad concept referring to any situation in which the utility level or consumption possibility set of one individual is influenced by an activity under the control of another. A *relevant externality* exists whenever the affected party has a desire to induce the acting party to modify his or her behavior with respect to said activity.

In order to get a better grasp of the issue of not fully consenting parties it is necessary to look closer at some very basic ideas behind economic behavior and market institutions. At the very foundation is the concept of exchange, i.e. the swapping of commodity bundles between individuals.

Exchange actually presupposes the existence of property rights and contract laws. Given the property right to something, the legal possibility of transferring the ownership of this something from one legal person to another, and the recognition by third parties of a contract thereto between consenting legal persons, the institution called a *market* is any formal or informal institution which allows for a meeting of the minds, negotiation of the terms of a contract and the ensuing exchange of property rights. Any such transaction will be termed an economic transaction.

It is not hard to imagine that a great deal of human activity may generate effects which are not explicitly covered by existing markets. Reasons for this may include:

- lack of defined property rights,
- lack of legal ability to
  - transfer ownership,
  - close contracts,
  - enforce contracts,
- lack of market institutions, or
- plain ignorance about all the effects and consequences of current activities and decisions.

Without unnecessarily restricting the further analysis by tying the externality concept directly to reasons for their existence the following definition is offered as a first attempt at formalizing the concept:

Definition 1 *An* externality *refers to a commodity bundle that is supplied by an economic agent to another economic agent in the absence of any related economic transaction between the two agents.*

Following this notion of an externality, it is important to keep separate the concepts of private and social costs.

[2] Cited in Cornes and Sandler (1986, p. 29).

Definition 2 *The* private costs *are those costs that an economic agent is imposing on itself.*

Definition 3 *The* social costs *are private costs plus those costs that an economic agent is imposing on other economic agents.*

It is obvious that the economic agent when making decisions will consider only the private costs[3]. The process of *internalization* of the full costs of the agents' actions involves changes in the institutional structure such that the agents face the full consequence of their decisions, that is there is equality between the private and social costs.

In order to analyze the externality concept in detail, and especially the notion of inefficiencies due to externalities will I need the basic tools of general equilibrium and ecouomic efficiency. Thus I turn to the description of a basic Arrow-Debreu type general equilibrium model.

2.1 A General Equilibrium Approach

General equilibrium modelling has a long tradition in economic theory (Debreu 1959). I will confine myself to a very brief verbal description of the standard Arrow-Debreu model (Arrow and Debreu 1954). The interested reader is referred to Quirk and Saposnik (1968), Arrow and Hahn (1971), or Cornwall (1984) for formal presentations, or Koopmans (1957), Varian (1984) or Jehle (1991) for standard textbook treatments.

2.1.1 The Arrow-Debreu Model

There are two types of economic agents in the economy: consumers and producers. There are l commodities, and in the Arrow-Debreu model a commodity is characterized by its physical characteristics as well as its geographical location, point in time and the state of the world (Debreu 1959, Koopmans 1957).

The consumers, indexed by $i = 1, \dots, n$, are characterized by their preferences, $\succeq_i$, consumption possibility sets, X_i, and endowments, ω_i. The consumption bundle of consumer i is denoted x_i. The preference relation is a binary relation such where "$x \succeq_i y$" means that "consumer i thinks that commodity bundle x is at least as good as commodity bundle y". The strict preference relation is denoted $\succ$.

The producers, indexed by $j = 1, \dots, m$, are characterized by their production possibility set, Y_j. Their production plans are denoted y_j, an l-dimensional vector.

Definition 4 *A* feasible allocation *of the resources in an economy is a vector of consumption and production plans* $(x_1, \dots, x_n, y_1, \dots, y_m)$ *such that*

$$\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \omega_i + \sum_{j=1}^{m} y_j$$
$$x_i \in X_i \quad i = 1, \dots, n,$$
$$y_j \in Y_j \quad j = 1, \dots, m.$$

Let p be the price vector. The *supply* function for firm j is defined as

$$s_j(p) = \{y_j^* \in Y_j : p \cdot y_j^* \geq y_j \quad \forall y_j \in Y_j\}. \tag{1}$$

[3]This is a blunt statement which should be modified somewhat. If the economic agent is aware of the costs imposed on (or benefits bestowed on) other economic agents, the agent may consider the potential consequences of damage to the agent's reputation or the possibility of legal or political actions. In the modern interpretation of economic behavior in a setting with interaction between different economic agents is such behavior a natural consideration.

The budget set for consumer i is the set of all affordable commodity bundles, i.e.

$$B_i(p) = \{x_i \in X_i : p \cdot x_i \leq w_i(p)\}$$

where $w_i(p)$ is the wealth function, i.e.

$$w_i(p) = p \cdot \omega_i + \sum_{j=1}^{m} \pi_{ij}(p \cdot s_j(p))$$

where π_{ij} is consumer i's share of firm j's profit. The *demand* function for consumer i is now

$$d_i(p) = \{x_i^* \in B_i(p) : x_i^* \succeq_i x_i \quad \forall x_i \in B_i(p)\}. \tag{2}$$

Definition 5 *A* Walrasian equilibrium, *or general competitive equilibrium, is an allocation-price pair $(x_1, \ldots, x_n, y_1, \ldots, y_m, p)$ such that*

1. *the $(x_1, \ldots, x_n, y_1, \ldots, y_m)$ allocation is feasible,*
2. *$x_i \in d_i(p) \quad \forall i$, and*
3. *$y_j \in s_j(p) \quad \forall j$.*

2.1.2 Basic Results

Without repeating all the technical assumptions of general equilibrium modeling, the following existence result is standard (Debreu 1959, Jehle 1991)[4].

Theorem 1 (Existence of General Equilibrium)
If the preferences, consumption possibility sets, and production possibility sets are convex (and closed sets), and the preferences are complete continuous pre-orders, then there exists at least one Walrasian equilibrium.

The concept of economic efficiency, or Pareto optimality, is defined next.

Definition 6 *A feasible allocation $(x_1, \ldots, x_n, y_1, \ldots, y_m)$ is a* Pareto efficient *allocation if there is no other feasible allocation $(x_1^*, \ldots, x_n^*, y_1^*, \ldots, y_m^*)$ such that*

1. *$x_i^* \succeq_i x_i \; \forall i$, and*
2. *$x_i^* \succ_i x_i$ for some i.*

The following are the two fundamental theorems of welfare economics.

Theorem 2 (Pareto Efficiency)
If the allocation-price pair $(x_1, \ldots, x_n, y_1, \ldots, y_m, p)$ is a Walrasian general equilibrium, then the allocation $(x_1, \ldots, x_n, y_1, \ldots, y_m)$ is Pareto Efficient.

Theorem 3 (Distributional Flexibility)
Suppose $(x_1^*, \ldots, x_n^*, y_1^*, \ldots, y_m^*)$ is a Pareto efficient allocation. Under appropriate convexity assumption will the allocation $(x_1^*, \ldots, x_n^*, y_1^*, \ldots, y_m^*)$ be a Walrasian competitive equilibrium for some price vector p^*.

[4] The existence of an equilibrium can be proved with much less restrictive assumptions than those stated here, see for example Arrow and Hahn (1971) and Mas-Colell (1985).

These three theorems together form the holy trinity of results in modern welfare economics. They state that markets are able to to allocate the resources, given initial property rights to the endowments, in an efficient manner. Furthermore, if the resultant efficient distribution is, somehow, not deemed equitable the endowments can be redistributed such that any desirable efficient allocation can be obtained through the market. Of course, this begs the question of how an equitable, or just distribution is determined and decided in a society. Furthermore, the underlying assumptions are thought to be so restrictive that it is very unlikely they can be met in a real economy.

2.2 Public Goods and Lindahl Equilibrium

The above standard Arrow-Debreu model deals with private goods only. Another important class of goods in an economy is public goods.

A good is said to be *excludable* if individuals can be excluded from consuming it. A good is *nonrival* if one individual's consumption does not reduce the amount available to other consumers.[5] Together do these two concepts characterize pure public goods.

Definition 7 *Goods that are not excludable and are nonrival in consumption are called* public goods.

Under *quantity rationing* is an individual able to freely choose a consumption level for some (nonrationed) goods, but is allotted certain amounts of other (rationed) goods. To sell any of the allotment is precluded and the allotment cannot be supplemented by additional purchases. Public goods are rationed or preallocated commodities in tbe this sense (Pollak 1969, Mäler 1974). Quantity rationed commodities are provided collectively, often without charge, and since the total amount supplied is available to each individual no individual controls her consumption level of these goods.

The equilibrium and efficiency analysis of public goods proceeds by considering the Lindahl equilibrium of a competitive economy with both private and public goods (Johansen 1963, Roberts 1974, Bergstrom 1976, Laffont 1988). The key to the Lindahl equilibrium is to consider the available quantities of the public goods as unique to each economic agent, but restricted to be equal across agents. Every private and public good is then assigned a price, noting that every public good has a separate price for each individual, and the analysis proceeds as usual. The prices for these public goods are called Lindahl prices.

In the Lindahl equilibrium each agent is facing common, or public, prices for the private goods, and individualized prices, or private prices, for public goods. Thus, by using individualized prices for the public goods it is indeed possible to sustain a Pareto efficient allocation with both private and public goods. This analysis can be made quite general, see for example Cornwall (1984, chapter 6.3). In particular does the trinity of theorems for private goods only economies carry over to economies with both private and public goods.

It may be appropriate to refer to one of the efficiency conditions for optimal provision of public goods (Samuelson 1954):

Condition 1 (Lindahl-Samuelson) *If a public good is provided at an optimal level, then the marginal cost of producing the good is equal to the sum of the marginal value of the good to* all *affected consumers of that good.*

[5] See Randall (1983) for detailed discussion of these concepts.

2.3 Lindahl Equilibrium in Externalities

The concept of a Lindahl equilibrium can be expanded to deal with externalities in general. Instead of having pure public goods of which all economic agents must consume the same amount, externalities have much of the same characteristics except that only a subset of the agents may be affected. That is, the externalities are characterized as non-excludable and non-rival in consumption for those consumers and firms which are affected. This idea is explored in full in Cornwall (1984, chapter 6), and also in Bergstrom (1976).

The inclusion of environmental externalities into general equilibrium theory is due to Mäler (1974), although Osana (1972) represents an early attempt at including externalities in a general equilibrium framework, and Shapley and Shubik (1969) investigates the shrinking core of replicated economy with externalities.

The lesson to be drawn from the use of the general equilibrium model is that an inefficient competitive equilibrium can be transformed into an efficient competitive equilibrium by operating all externality markets costlessly and competitively. This point is elaborated on in a classic paper by Arrow (1970).

Condition 2 (Arrow) *In an economy with a complete set of functioning markets will all externalities be internalized through the parametric market prices.*

3 Property Rights and Coase Theorem

In one of the arguably most cited and influential articles in economics did Coase consider the relationship between property rights, liability law, markets and externalities (Coase 1960). This paper has spawned an enormous literature of which not everything is equally memorable. Let me point the interested reader to a few papers, for example Cheung (1973), Randall (1972), Randall (1974), Dahlman (1979), and Bromley (1986), and also the books by Cornes and Sandler (1986) and Spulber (1989).

The main result attributed to Coase's paper is the following theorem:

Theorem 4 (Coase)
While some assignment of legal rights is essential for achieving economic efficiency, the particular allocation of those rights does not affect the efficiency of market outcome in the absence of transaction costs.

Let me strongly emphasize the crucial assumption in this theorem, and that is the lack of transaction costs. Because as soon as it is allowed for transaction costs the conclusions are dramatically altered. Indeed, from an efficiency point of view should the legal rights be assigned to that party whose transaction costs are smallest. This has given rise to a large literature on its own regarding the efficiency of formal laws and legal practices (Posner 1977, Cooter and Ulen 1988).[6]

The other point to note is that the theorem only says something about the efficiency properties of the resulting allocation. It is well established in the literature that different assignments of legal rights may have major distributional impacts, although all equilibrium allocations are efficient (Randall 1972, Randall 1974).

Conservative economists have for a long time relied on the Coase Theorem to argue that free bargaining between self-interested economic agents will resolve any *relevant* externality. Those

[6] Coase's Nobel Lecture is also well worth reading as to better understand what was intended by Coase in his original paper (Coase 1992).

externalities still prevailing are Pareto irrelevant since the costs of removing them exceeds the gains from internalizing them (Buchanan and Stubblebine 1962). Thus, some have concluded, externalities is a non-issues in economies with extensive markets and well-defined property rights.

4 Pigouvian Taxes

If the involved parties cannot internalize an externality with bargaining in the sense of Coase or by introduction of additional markets in the sense of Arrow, it may be possible to mitigate the inefficiencies caused by the externalities by government intervention. Pigou (1924) suggested that externalities might be internalized by means of appropriate taxes and/or subsidies.

The general setup of characterizing the Pigouvian approach is very well characterized by Baumol and Oates (1988, chapter 4), and in Cornwall (1984, chapter 6) and will not be repeated here.

Condition 3 *By charging the appropriate taxes and subsidies on externalities, and with the necessary lump-sum transfers, can any and all externalities be internalized, and the resulting resource allocation will be Pareto efficient.*

5 Regulation with Incomplete Information

The Pigouvian approach with its reliance on big government, optimal taxes and subsidies has for decades been the liberal economists standard response to any sign of externalities. However, the modern research agenda in microeconomics with its focus on private and asymmetric information shows clearly that the informational requirements of the Pigouvian approach is utterly utopian. In real-world situations with private and asymmetric information, where information gathering and processing demand resources on its own, it turns out that entirely different approaches are required for regulating generators of externalities[7].

This strand of literature starts with the seminal work on demand-revealing mechanisms for public goods (Vickery 1961, Clarke 1971, Groves and Ledyard 1977, Green and Laffont 1977) and team theory (Groves and Radner 1972, Groves 1973). And continuing on with the more general problem of mechanism design (Harris and Raviv 1981, Myerson 1983, Groves, Radner and Reiter 1987). A very readable and influential paper on the early work on mechanism design is Hurwicz (1973). Textbook treatments can be found in (Hess 1983, Campbell 1987). This is approach to economic analysis is followed through in Blad and Keiding (1990).

Of particular relevance is the modern literature on regulation of monopolists (Baron and Myerson 1982, Sherman 1989, Train 1991) or regulation more general (Besanko and Sappington 1987, Spulber 1989). The interested reader is recommended to purview any of these books: Laffont (1979), Cornes and Sandler (1986), Laffont (1988), Spulber (1989), Train (1991), and especially Laffont and Tirole (1993).

6 Efficient Externality Levels

Although, in my opinion, the Pigouvian approach has only limited applicability it provides a clean model for a clear conceptual analysis of externalities. The point I want to make is that one lesson emerging from the literature on environmental economics is that in a situation with a

[7] The same informational constraints may also be a stumbling block for the implementation of the Coasian approach where property rights and liabilities are assigned to the parties such as to minimize the transaction costs.

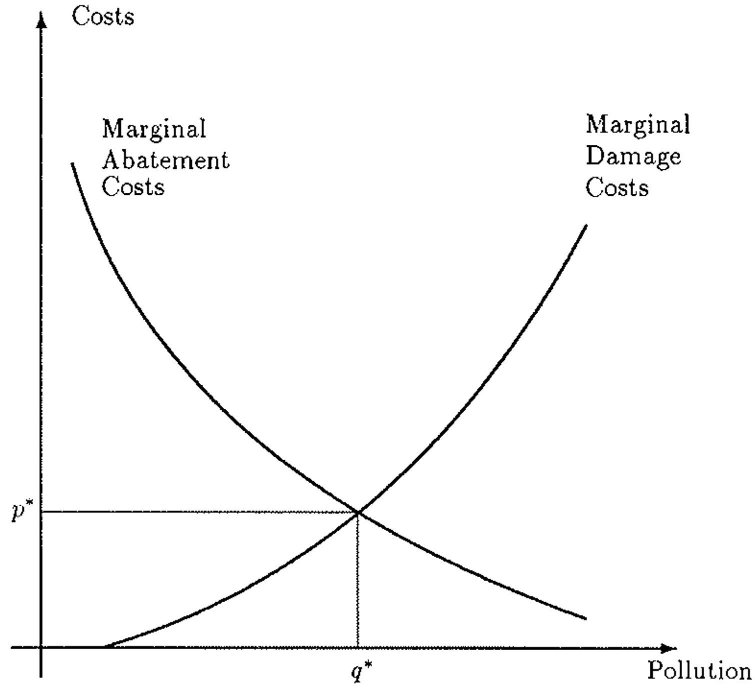

Figure 1: Efficient pollution level (q^*) and the corresponding environmental value of damages (p^*).

potential externality the complete removal of the externality is not always the efficient solution. Rather, it turns out that there often is an efficient level of pollution, i.e. the efficient society is, of course, efficiently dirty.

This can be nicely illustrated in with help of the graph in Figure 1. The marginal abatement cost curve represents the costs of reducing some undesirable pollution with a small amount. The marginal damage curve measures the value to the affected population of a small increase in the pollution level.

The *efficient pollution level* is now that amount of pollution at which the marginal abatement costs equals the marginal damage caused by that pollution level. The monetary value, p^*, which equals the intersection of the two marginal curves at this pollution level represents the shadow price of the environment. This is indeed the optimal Pigouvian tax to use if a regulator wants to implement the optimal or efficient pollution level through the use of pollution charges, i.e. internalize the damages to the offending economic agents. If, on the other hand, the regulator wants to implement the efficient pollution level through a command and control mechanism, then the regulator should issue an emission permit in the amount q^*.

Condition 4 *At the efficient pollution level will the the marginal damage equal the marginal abatement costs.*

Now, this is the task at hand when considering the external costs of energy production. Let me make this point once more:

- In order to determine the efficient level of pollution and the value of the environment, *both* the these curves must be known to the analyst.

- Furthermore, the external cost of an activity *cannot* be determined without knowing the damage function.

There is a number of studies looking at this particular issue for energy production. A nice review was done by Shep Buchanan for the New York State Energy Research and Development Authority (Ottinger, Wooley, Robinson, Hodas and Babb 1990, chapter 3). Another study, although less ambitious in scope, was completed last year in Norway (Selfors 1992).

7 Measurement of Environmental Values

This leads me to the last topic of my lecture, the valuation of nonmarket goods. There seems to be an asymmetry in the current research effort in terms of valuation. My previous point that both the damage and the abatement cost curves are needed for determining (approximately) the efficient level of externalities is not at all reflected in the research effort neither on valuation in general nor on external effects of energy production in particular.

During the last twenty years a large effort has been expanded towards developing and refining various methods for estimating the damage function. (More on the in a moment.) At the same time, is it easy to find examples of empirical studies of the external costs of energy technologies which are using abatement costs as an estimate of the environmental costs. The logical fallacy is obvious — *the environment is at any place in space and at any point in time valued at whatever efforts we are putting into abatement, mitigation and restoration activities.*

7.1 The Total Value Approach

As I see in the literature on energy production and policies both ignorance and a lack of trust in the nonmarket valuation techniques[8], let me argue for continued and increased use of well executed nonmarket valuation studies. Such studies are at the present not that common in Europe, but this is growing research field and an area of expansion for consulting work[9].

The conceptual starting point is that the relevant value of any environmental asset is captured in the *total value* concept (Randall 1991). In the total value concept is included a number of different subcomponents, i.e.

1. current use value which is the value of current use of a resource, both consumptive and non-consumptive use,
2. future use value which is the value, as seen today, of all future use, both consumptive and non-consumptive, of a resource, and
3. option value which is the premium (or discount) associated with acquiring an option for future use of a resource where supply of or demand for the resource is uncertain (Bishop 1982, Meier and Randall 1991).

These three components add up to the *total use* value of the resource. The *non-use value* of a resource is often said to be motivated be three factors:

1. existence value,
2. bequest value, and

[8] A short sample may include Hohmeyer (1988), Stirling (1992), and Friedrich and Voss (1993).

[9] My colleague Ståle Navrud and I are in the process of completing a review of the European experience with nonmarket valuation techniques. Also see the volume of country reports edited by Navrud (1992).

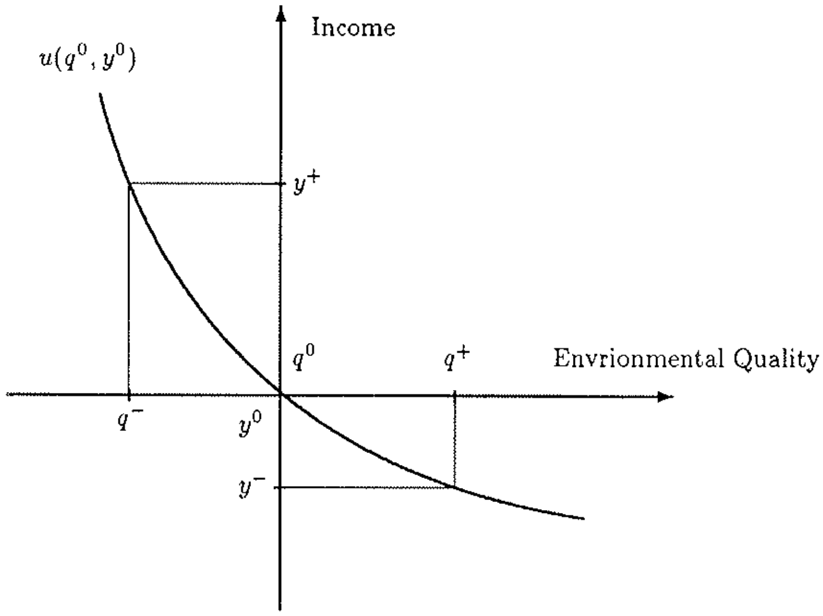

Figure 2: The total value function for a change in income (y) and available quantity (q) of an environmental good.

3. intrinsic value.

Taken together do total use value and non-use value constitute the total value of a resource. And it is changes in this value which is relevant for cost-benefit analysis and which is the value concept behind the marginal damage curve in figure 1.

7.2 The Bid Function

A most useful theoretic device for development of valuation methods is the *bid function* (Bradford 1970). Let us consider an individual whose utility level is determined by the income level, y, and the available quantity of environmental good, q. All other goods and services are ignored in order to simply the analysis. The utility function for the individual can be written as $u = u(y, q)$.

In Figure 2 is depicted an example of how the bid function may look for an individual whose initial utility level is at $u^0 = u(y^0, y^0)$. The compensating variation, or the willingness-to-pay, for an increase in the available quantity of the environmental good from q^0 to q^+ is that change in income which will keep the individual on the same utility level. From the figure the compensating variation is seen to be equal to a reduction in income from y^0 to y^-.

The compensating variation, c, is formally defined by

(3) $$u^0 = u(y^0, q^0) = u(y^0 - c, q^+).$$

Furthermore, the compensating variation for a reduction in available environmental goods from q^0 to q^- corresponds to an increase in income from y^0 to y^+.

7.3 Available Methods

A number of valuation methods are available. See Braden and Kolstad (1991) for a collection of state-of-the-art reviews. Previous reviews include Freeman (1979) and (Pearce and Markandya 1989).

One useful classification of the available methods is:

1. methods based on *constructed markets*, and
2. methods based on *surrogate markets.*

Of the constructed market methods is the *contingent valuation* the most prominent and most widely used method. The roots of the method goes back to Randall, Ives and Eastman (1974) and Brookshire, Ives and Shulze (1976). The standard reference on the method is Mitchell and Carson (1989).

There are available two surrogate market valuation methods which has been used extensively. One is based on the concept of weak compelemtarity (Mäler 1974) with the *travel cost* method as the most common technique (Anderson and Bishop 1986, Johansson 1987). The other method is the *hedonic pricing* method (Rosen 1974, Palmquist 1991).

These methods are not equivalent, and are to be used with the intended purpose of the study in mind. Some discussion and recommendations with respect to the applicability of the various methods are presented in Selfors (1992).

8 Conclusions

In terms of the appropriate public policy response to externalities much of the economic literature (and legal literature as well) is not more than dogmatic statements about preconceived political positions with respect to the glorious suitability of laissez-faire and free markets or the big benevolent government, respectively. Some of this discussion is peculiar to the American political and judicial system. Instead of repeating much of that debate, let me add a few points of more relevance to the European political realities.

It is not always possible to implement the Arrowian or Coasian approach to externalities by introducing complete sets of market and full property rights. Implementation of Pigouvian taxes run into enormous informational problems. However, in a regulatory context does the emerging methods of incentive based regulation look promising. Still, such regulation will require information of both the demand and supply side of the externality. Thus valuation of nonmarket good becomes an important and integral part of the regulatory process.

One important difference between the (North-American) literature on policies toward externalities and the European reality is the crucial role played by the process of obtaining siting permits. In a setting with the need for a permit in order to establish an energy production facility we find that:

1. the petitioner, a private investor (?), will require expected positive private profits from the project, and

2. the petitioner must demonstrate a favorable social benefit-cost ratio of the project in order to persuade the governing institutions to issue the necessary permits.

Thus, we are seeing an increased interest among firms in the energy sector in social cost-benefit analysis for use in their permit application process. This may not be a perfect way to approach externality issues in general, but it shows an interesting twist to the standard regulatory process which avoids some of the most sever informational problems.

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Renewables and the full costs of energy

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Renewables and the full costs of energy

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The central obstacle for a widespread use of renewables are the relative prices of these forms of energy not their availability. The paper shows that the present prices of non-renewable energy sources are heavily subsidized by not including the costs of health and environmental damages as well as costs handed on to future generations. If these costs are taken into account the relative costs of renewables look far more favourable than present market prices show.

Keywords: Renewable energy; External effects; Social costs

In his article introducing the series of papers on renewable energy Jackson[1] poses the question 'Is renewable energy our greatest hope to bring a satisfactory resolution of the 'thermodynamic interlude' or will it prove to be a deceitful signpost, a false promise on the inevitable road to disorder?'. This question can be split up into two parts. First, we have to ask whether renewables will be able to supply close to 100% of human needs for energy services in the long run? If this is possible, the second question will be, at what cost can these energy services be delivered?

Previous papers in the series have shown that solar energy is received by the earth in abundant quantities as compared to our present use of energy. Sørensen[2] gives as estimated recoverable energy stream received by the earth of about 1 000 TW with a total annual energy income (resource base) of about 90 000 TW. According to the World Development Report 1990[3] worldwide consumption of technical energy amounted to about 70 000 ~~h~~/year in /TWh 1988. If we consider an average availability of renewable resources of 1 000 TWh/year – a rather modest assumption – about 70 TW of capacity would be required to cover the world's present demand. Thus, we can conclude that the availability of renewable energy resources will not pose a problem.

This brings us to the second part of the question, the cost of the energy drawn from renewable sources. Presently a standard argument is that renewables will play a minor role in the future energy supply because this form of energy is too expensive. In the long run this argument cannot hold because non-renewable energy sources will be exhausted. At that point in time mankind will have to fall back onto renewable energy sources at any price, because in many instances energy cannot be substituted as a production input or as an essential input into consumption activities. This point of exhaustion for non-renewable energy sources may be a few hundred years in the future if no restrictions are applied.

However, the present discussion on global warming due to the anthropogenic emissions of greenhouse gases, points out that fossil fuels cannot be used at the present pace for decades and centuries to come, if we do not want to endanger global climatic stability. At the same time nuclear fission will only be able to extend our time frame if we resign ourselves to breeder technology with all the potential risks of plutonium fuel cycle and at energy costs which can be guessed at today. It is presently unknown whether nuclear fusion will ever be able to contribute significantly to the energy supplies of mankind, not to speak of the actual costs of such energy even if it could be supplied commercially. Thus, renewable energy may already be needed to supply a major part of the energy used by mankind a few decades from now. Consequently our question of relative costs boils down to a short-to mid-term comparison of renewable energy sources with presently established conventional energy systems.

COSTS TO BE CONSIDERED

The statement that renewable energy sources are too expensive to be used substantially in the short or mid

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term is generally based on a very narrow definition of costs. Cost comparisons usually just take into account the so called 'internal' cost elements involved in the production and distribution of a product. Other cost elements which are payed for by third parties not involved in the production or consumption of the product do not show up in prices and are not considered in standard cost comparisons. These cost elements are normally referred to as external or social costs.[4] In this paper the term social costs will be used. Examples of such social cost elements for energy production and use are: the damage done to forests by acid rain, which are paid for by the forest owners; the consequences of massive global warming due to anthropogenic emissions of greenhouse gases; or the health impacts of major nuclear reactor accidents such as Chernobyl. No energy consumer is charged any of these costs, which result from the use of conventional energy sources.

If conventional energy sources and different technologies for the utilization of renewable energy sources are compared with respect to the levels of social costs incurred, it appears that most renewables have considerably lower social costs. Thus, the seemingly cheap conventional energy sources may be rather expensive to society. If this is the case, the statements regularly made on the comparative internal costs may be vastly misleading and investment decisions taken on these grounds may acrue substantial losses to society.

The question of relative social costs of electric power had been heavily discussed internationally since 1988 when a first comprehensive report on the subject[5] was published. This paper will try to summarize the results of that discussion and to draw some first conclusions with regard to the question of the relative total costs of an energy supply strategy based on renewable energy sources.

SOCIAL COSTS TO BE CONSIDERED

There are a number of different energy costs categories born by third parties which ought to be taken into account in the comparison of different energy technologies. The following list gives an impression of the range of effects to be considered:

- Impacts on human health: short-term impacts like injuries; long-term impacts like cancer; intergenerational impacts due to genetic damage.
- Environmental damages to: flora; fauna; global climate; materials.
- Long-term costs of resource depletion.
- Structural macroeconomic impacts such as employment effects.
- Subsidies such as: R&D subsidies; investment subsidies; operation subsidies; subsidies in kind for: infrastructure and, evacuation services in case of accidents.
- Cost of an increased probability of wars due to: securing energy resources (eg the Gulf War); proliferation of nuclear weapons know how through the spread of 'civil' nuclear technology; costs of the radioactive contamination of production equipment and dwellings after major nuclear accidents; and
- Psycho-social costs of: serious illness and death; relocation of population due to construction or accidents.

This list of possible costs excluded from the normal pricing of energy is not exhaustive but it gives an impression of the range of costs which need to be considered before we may conclude that a certain energy technology is too expensive to be used.

Although it is relatively easy to enumerate a substantial number of social cost categories, which are obviously not taken into account today, it is rather difficult to quantify many of these effects and to put monetary values on them. As in the case of global warming due to anthropogenic emissions of greenhouse gases, we can describe a number of probable effects in qualitative terms while we can only guess others. The latest computer models allow us to come up with some first quantifications of probable global temperature rises, but a sound analysis of the damages incurred and the damage costs to be expected seems presently impossible. We can only guess possible orders of magnitude of such damages. In general we are in the situation of a navigator trying to estimate and compare the size of different icebergs ahead of him while he can only see the tips of these icebergs in the fog.

So far most empirical studies of the problem have focussed on a few problem areas, mostly on effects on human health and environmental damages.[6] It should be pointed out, however, that there is a growing literature addressing different facets of the problem at the theoretical as well as at the empirical level.[7]

EMPIRICAL EVIDENCE ON SOCIAL COSTS

The empirical evidence presented here is based on the present author's latest research on the subject[8] taking into account much of the international discussion of the last three years. This work was centred around a comparison of conventional electricity generation based on fossil and nuclear fuels with wind energy and photovoltaics applied in Germany. These areas of social costs covered are: environmental effects; impacts on human health; depletion costs of non-renewable resources; structural macroeconomic effects; and, subsidies. Due to the scarce availability of empirical data and some fundamental problems in monetizing, a number of effects have *not* been quantified or specified in monetary terms by the author so far.[9]

Accordingly one should interpret the results presents in the following as a preliminary overview producing rather crude figures. Wherever doubt exists, assumptions have been made favouring conventional energy and counter to the underlying hypothesis – that the social costs of systems using renewable energy sources are considerably lower than those of systems using conventional energy. Thus, the author feels confident that the difference in the real social costs between the renewables considered and the conventional electricity generation in Germany is even larger than these results show.

The estimated specific health and environmental costs of electric power production from fossil fuels have been based on available studies trying to monetize the overall damages of air pollutants in Germany. Little information is available on the possible damages of CO_2 emissions through global climatic changes. In general the social costs of environmental and health impacts have been measured as roughly attributable damage costs. In contrast to this approach other authors favour control cost estimates as proxies for the actual damage costs, as these are easier to analyse, while some advocate contingent valuation procedures like 'willingness-to-pay' analyses, which allow a broader range of impacts to be covered than direct costing. Because the control cost approach allows for a substantial level of arbitraryness due to the emission level allowed and because the contingent valuation methods result in somewhat less reliable results, these approaches have been chosen for the analysis only in rate cases. Control costs have been used for some first estimates on CO_2 emission impacts through global climatic change. The figures used are based on an overview of US studies on the subject published by Koomey.[10]

As the author has shown in other publications[11] there is strong evidence that the prices of non-renewable energy sources do not reflect long-term scarcity, because major aspects of intertemporal allocation like sustainability and intertemporal justice are presently disregarded in favour of extremely high and wasteful energy consumption. If energy prices are to steer long-term sustainability, simple models for the calculation of reinvestment costs and appropriate surcharges need to be drawn up. First estimates of such costs are included in the figures quoted in the following.[12]

In the case of macroeconomic effects the structural differences in the production and consumption resulting from different energy scenarios have been analysed. These are mainly changes in GNP and employment.

AGGREGATED RESULTS AND COMPARISON OF SOCIAL COSTS

When the quantified social costs of conventional energy systems for the production of electricity based on fossil fuels are totalled and standardized for the production of 1 kWh, gross social costs in the range of 0.03 to 0.16 DM/kWh result (1989 DM). (The value of 1 DM at the time of writing is about US$.6 or approximately £0.37.) For electricity generated in nuclear reactors (not considering fast breeder reactors) gross social costs in the range of 0.1 to 0.7 DM/kWh result. A weighted average for these gross social costs according to the fuel composition found in (West) Germany's electricity generation in 1984 is 0.05 to 0.29 DM/kWh. Table 1 summarizes the social costs of different means of electricity generation quantified in monetary terms. In order to facilitate a net analysis of the social costs (or benefits) of renewables the social cost figures for conventional electricity carry positive signs in Table 1, while each negative effect of renewables shows a negative sign. In this way the calculation of the difference in the social costs can easily be done by adding position d.1 through d.4 for wind energy (e.1 through e.4 for PV) including the avoided average gross social costs of conventional electricity generation as position d.4, which is the total calculated in part c of the Table.

When one considers the social costs and benefits of electricity generated by wind energy – with the social costs of present electricity generation included as avoided costs (d.4) – total social net benefits in the range of 0.05 to 0.28 DM/kWh result. This can be considered as a probable range for the minimum social net benefits of wind energy. The sum of net social benefits for photovoltaic electricity supplied to the public grid lies between 0.06 and 0.35 DM/kWh after all netting is done. Again, this is only an estimate of a probable range for the minimum social

Table 1. Comparison of the social costs calculated by Hohmeyer in 1988 and the results of recalculations performed in 1990 (all figures in Pf/kWh (1982)).

Gross social costs of electricity generated from fossil fuels (all figures are estimated minimal social costs)	**Hohmeyer (1988)**	**New calculations (1990) including CO_2**		
		Emissions 1982		**New power plants 1990**
Environmental effects	1.14 – 6.09	2.6 – 10.67		2.05 – 7.93
Depletion surcharge (1985)	2.29		0.67 – 4.71	
Goods and services publicly supplied	0.07		0.06	
Monetary subsidies (including accelerated depreciation)	0.32		0.30	
Public R&D transfers	0.04		0.02	
Total	3.86 – 8.81	3.65 – 15.96		3.11 – 13.03
Gross social costs of electricity generated in nuclear reactors, excluding breeder reactors (all figures are estimated minimal social costs)				
Environmental effects (human health)	1.20 – 12.00		3.48 – 21.0	
Depletion surcharge (1985)	5.91 – 6.23		4.88 – 47.72	
Goods and services publicly supplied	0.11		0.11	
Monetary subsidies	0.14		0.14	
Public R&D transfers	2.35		1.46	
Total	9.71 – 20.83		10.06 – 70.13	
Average gross social costs of the electricity generated in Germany in 1984		Fossil power plants 1982		New fossil power plants 1990
Costs due to electricity from fossil fuels (weighting factor 0.705[a])	2.87 – 6.56	2.58 – 11.25		2.19 – 9.19
Costs due to electricity from nuclear energy (weighting factor 0.237[b])	2.48 – 5.32		2.38 – 16.2	
Total (conventional electricity)	5.35 – 11.88	4.96 – 27.87		4.57 – 25.81
Net social benefits of wind energy				
Environmental effects (noise)	(–)0.01		(–)0.01	
Public R&D transfers (estimate)	–0.26 – (–)0.52		–0.16 – (–)0.33	
Economic net effects	+0.53 – (+)0.94		+0.47 – (+)0.78	
Avoided social cost of present electricity generation	+5.35 – (+)11.88	+4.96 – (+)27.87		(+)4.57 – (+) 25.81
Total social benefits rounded to two digits	+5.6 – (+)12.3	5.26 –28.32		4.87 – 26.25
Mean	(+) 8.9	16.8		15.6
Net social benefits of solar energy (PV)				
Environmental effects	(–) 0.44		(–)0.44	
Public R&D transfers (estimate)	–0.52 – (–) 1.04		–0.33 – (–)0.65	
Economic net effects (not including 1982 figures)	+2.40 – (+) 6.65		+2.35 – (+)8.35	
Avoided social cost of present electricity generation	+5.35 – (+)11.88	+4.96 – (+)27.87		(+)4.57 – (+)25.81
Total social benefits rounded to two digits	+6.8 – (+)17.1	+6.54 – (+)35.13		(+)6.16 – (+)33.07
Mean	(+)11.9	20.8		19.6

Notes: [a] Old weighting factor 0.7444; [b] Old weighting factor 0.2556.
Source: Hohmeyer, *op cit*, Ref 4, p 8.

net benefits. All assumptions underlying these figures minimize the advantages of renewable energy sources. Therefore, in cases of doubt, the probable social benefits of the renewable energy sources analysed are considerably greater than these figures show. This point has been borne out by all national and international discussions on the first results published by this author.[13]

Even without including all social costs and even with a deliberate bias against renewable energy sources, the net social benefits in monetary terms of wind and photovoltaic energy are comparable with the basic market prices of conventionally generated electricity. Thus, any statement on the 'high relative costs of renewables' has to be reconsidered in the light of a full cost analysis taking into account the substantial differences in social costs between conventional electricity generation and renewables. The handling of the issue of social costs may have a considerable effect on the time schedule for the market introduction and diffusion of seemingly expensive technologies utilizing renewable energy sources.

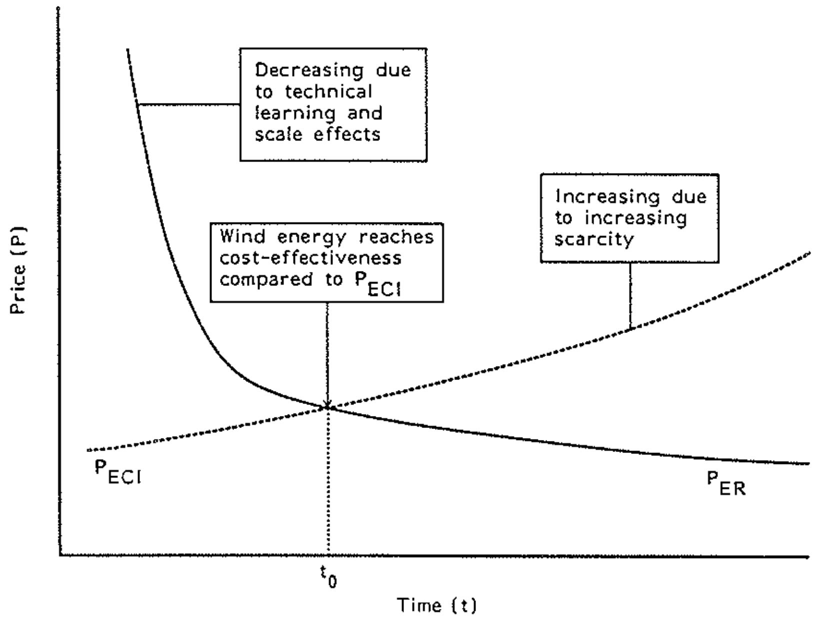

Figure 1. Cost development of two competing technologies for electricity generation over time (no social costs considered).

Source: Hohmeyer, *op cit*, Ref 14.

Notes: P_{ER}: wind energy as an example for renewable energy sources; P_{ECI}: conventional electricity, only internal costs.

EFFECT OF SOCIAL COSTS ON THE COMPETITIVE SITUATION AND MARKET DIFFUSION OF RENEWABLES

How can the impact of considering social costs on the competitive position of a new technology *v* an established one be analysed? One way is to examine a two-product market, as Figure 1 portrays. The costs of the established technology are increasing gradually due to rising exploration and mining costs, for example, while the costs of the new technology based on renewable energy sources are decreasing considerably over time due to technological learning. One can show such developments empirically for conventional electricity and wind or solar energy. At the point t_0, the new energy technology reaches cost effectiveness if one considers no social costs. The substitution process can start at t_0.

Figure 2 shows the effect of including the net social costs. These are defined as the difference between the social costs of conventional electricity generation and those of the new technology. A static application of the social costs for a base year (eg 1988) results in a parallel projection of conventional electricity's market price curve. This results in a new intersection with the renewable energy cost curve and shows that the new energy technology reaches cost effectiveness at $t_0 - \Delta\text{-}t$ at t_1. If the social costs reach a sizable order of magnitude, then a distorted competitive situation results: The wrong price signals are given through the markets to the potential investor for the choice of energy technologies.

Because cost effectiveness does not lead to instant technology substitution but to a substitution – or market diffusion – process that may easily stretch over 20 or more years, one can picture the impact of not considering social costs as a shift of $\Delta\text{-}t$ in the new technologies market penetration curve as shown in Figure 3. If one does not consider social costs, then the whole diffusion process is delayed by this time span as compared with the best possible diffusion time schedule for society.

The social costs empirically quantified in Table 1 are applied in the following analysis of the future competitive position and market diffusion of wind and photovoltaic solar energy. Figure 4 shows the impact of including social costs on the competitive situation and on the resulting market diffusion of wind energy systems in Germany. All assumption for this analysis are given in Table 2. It should be pointed out that there are different assumptions on the percentage of the electricity produced, which is fed back into the grid for wind energy systems (80%) and photovoltaics (50%). This explains the different

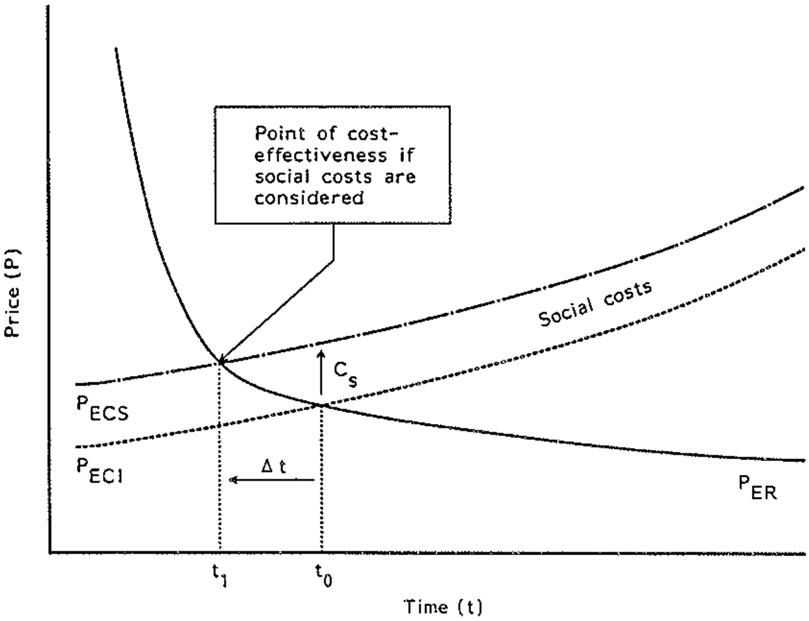

Figure 2. Cost development of two competing technologies for electricity generation over time (social costs considered).

Source: Hohmeyer, *op cit*, Ref 14.

Notes: P_{ER}: wind energy as an example for renewable energy sources; P_{ECI}: conventional electricity, only internal costs. P_{ECS}: conventional electricity including social costs.

prices of conventional electricity which the renewables have to compete against, as the buyback rates are lower than the avoided costs for electricity used for own consumption.

For the electricity costs of small wind energy systems of 50 to 100 kW nominal power, a cost curve has been derived on the few available German wind energy cost figures for the period 1980–86 and on well documented Danish wind energy data for the years 1975–85. As we see from Figure 4(a) the German wind energy cost curve intersects with the market price curve of the electricity to be substituted at point *A*(2002). At this point in time wind energy produced by a private autoproducer is competitive with the electricity from the grid which is to be substituted at market prices not including social costs.

Adding the lower range of the estimated minimum net social costs (0.05 DM/kWh based on new fossil power plants) to this market price curve results in a second curve for the substituted electricity where point *B*(1991) is the new point of cost effectiveness for wind energy. Adding the upper range of the minimum net social costs of electricity (0.26 DM/kWh based on new fossil power plants) to the market price of substituted electricity gives a third intersection *C*(1981) as new point of cost effectiveness for wind energy. Figure 4(b) shows the resulting change in market penetration of wind energy systems resulting from this altered competition situation. We can conclude that, including social costs, wind energy is competitive considerably earlier than market prices show. Accordingly, the market penetration of wind energy systems starts much earlier.

Figure 5 illustrates the situation for photovoltaics in Germany competing with electricity from the grid. The cost degression curve shown has been estimated on the basis of eight different studies on photovoltaic energy cost developments. Later comparison to other analyses has shown the estimated cost degression to be rather conservative. For a more favourable climate such as southern Spain or southern California the PV costs can almost be divided by factor two due to the greater amount of solar radiation per square metre and year. While the cost of electricity generation in isolated locations on the basis of diesel generators may be high as 0.5 to 1.5 DM/kWh depending on the specific transportation costs.

As in the case of wind energy, intersection *A*(2019) gives the point of cost effectiveness for photovoltaics if no social costs are considered. Including the lower estimate of the net social costs as compared to conventional electricity (based on new technology for fossil plants) of 0.06 DM/kWh leads

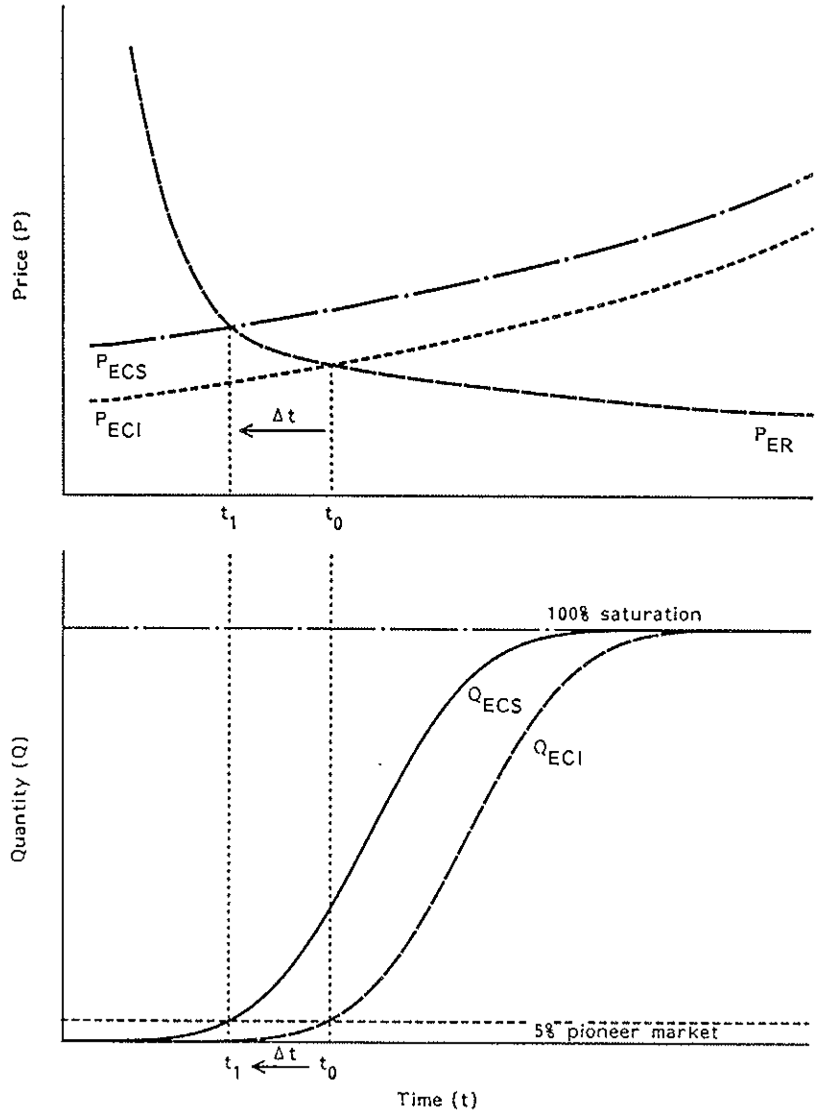

Figure 3. Market diffusion of wind energy due to handling of social costs.
Notes: Q_{ECI}: market diffusion curve of wind energy (only internal costs); Q_{ECS}: market diffusion curve of wind energy taking social costs into account; P_{ER}: wind energy as an example for renewable energy sources; P_{ECI}: conventional electricity, only internal costs. P_{ECS}: conventional electricity including social costs.

to considerably earlier cost effectiveness at $B(2014)$ with the inclusion of the higher estimate of 0.33 DM/kWh (new fossil plants considered) giving an even earlier point $C(2002)$ of reaching competitive cost. Figure 5(b) illustrates the shifts in market penetration accordingly. Due to the substantially higher costs of photovoltaics today, the inclusion of social costs will not have an instant effect on its market introduction as in the case of wind energy. Considering the short- to mid-term future situation one or two decades from now, the inclusion of social costs changes the competitive situation and market diffusion of photovoltaics dramatically.

CONCLUSIONS ON THE REAL COSTS OF ENERGY

After we have seen that renewables can supply more than the necessary energy services needed by mankind we found that – all costs considered – renewables have considerably lower relative costs than market prices show. This is mainly due to the fact that we are subsidizing our present low market prices of conventional energy sources by not accounting for major cost shares due to environmental and health damages as well as by wasting energy

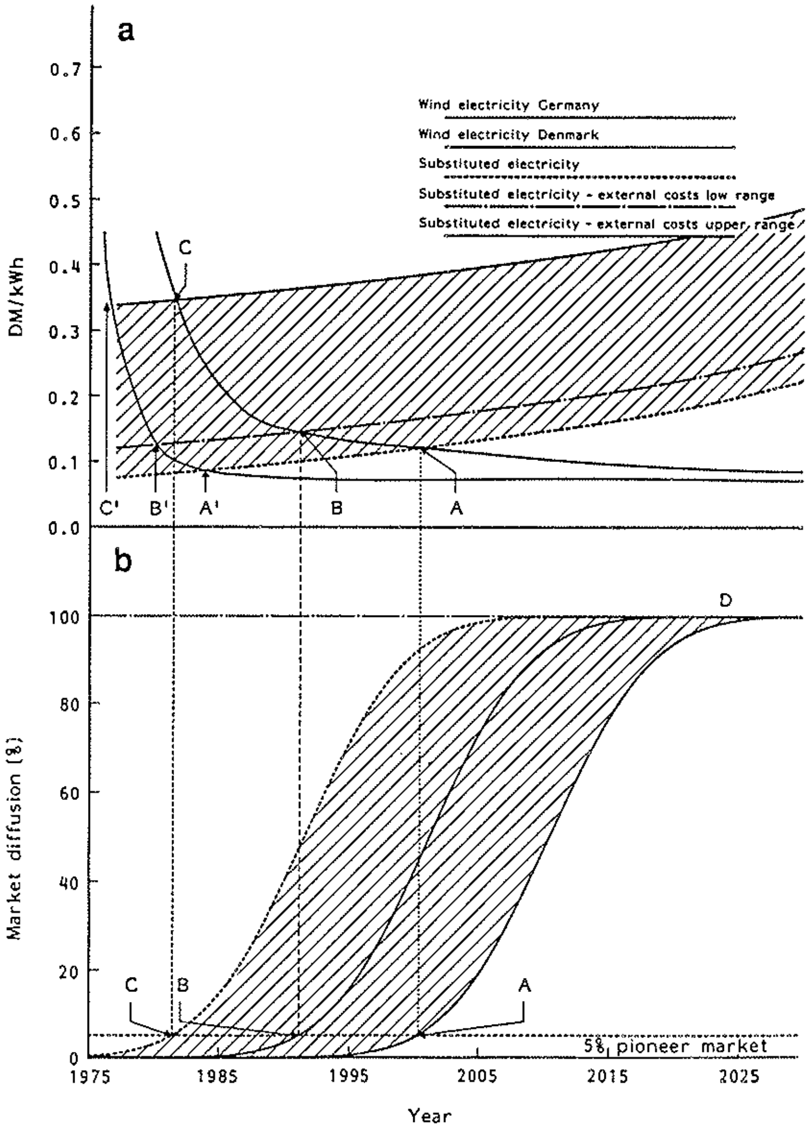

Figure 4. Influence of social costs on starting point of market penetration of decentralized wind energy systems and future market diffusion to year 2030.

Notes: (a) costs for electricity from wind energy compared with costs for substituted conventional electricity; (b) market penetration of wind energy based on costs shown in (a).

at the expense of future generations. Once we stop costs being largely laid on parties not involved in the consumption of the energy we find that renewable energy sources (as well as the rational use of energy) really have cost advantages. This may be concluded, although the results presented are far from being final and exhaustive, because practically all assumptions made in cases of doubt lead to underestimating the true social costs of conventional electricity systems.

An energy policy will be needed to internalize all social cost elements not presently included in energy prices to secure a sound future development of our energy systems and a sustainable development for mankind. This can be done by charging taxes or levies against the activities inducing substantial social costs. If this does not seem to be feasible in the short run, an increase in the buyback rate paid for electricity produced from renewable energy sources can be a starting point for setting things right.

In Germany, the Federal Government has enacted a law which has been in effect since 1 January 1991, to increase buyback rates for electricity from wind turbines and photovoltaic installations to 90% of the electricity rates charged by the utilities to final consumers. This has led to roughly doubling

Table 2. Assumptions underlying the analysis of social costs and the impact on the competitive situation of wind and photovoltaics.

General assumptions	
Price of substitutable conventional electricity (1982)	25.1 Pf/kWh
Working price (62.5 %)	15.6 Pf/kWh
Payment for electricity supplied to the public grid	6.5 Pf/kWh
Real price escalation of conventionally produced electricity	2%/year
Real interest rate for the financing of new investments in wind and photovoltaic machines	5%/year
Market potential for wind and photovoltaic machines	20 TWh/year
'Pioneer market' (5% of the market potential)	1 TWh/year
Time period for the diffusion phase (5% to 95 %)	20 years
Assumptions about wind energy	
Share of wind energy consumed by owner	20%
Share sold to utility	80%
Compound gain of wind electricity (1982)	10.2 Pf/kWh
Compound gain of wind electricity based on working price assumption	8.3 Pf/kWh
Life expectancy of wind energy facilities	15 years
Annuity	9.63 %/year
Operating and maintenance cost	1.5%/year
Wind energy costs in West Germany	
1980	44.8 Pf/kWh
1986	19.6 Pf/kWh
1990	15.0 Pf/kWh
2000	12.1 Pf/kWh
2010	10.2 Pf/kWh
2030	8.4 Pf/kWh
Wind energy costs in Denmark	
1980	12.5 Pf/kWh
1986	9.1 Pf/kWh
1990	7.6 Pf/kWh
2010	7.4 Pf/kWh
2030	7.0 Pf/kWh
Assumptions about photovoltaics	
Share of photovoltaic energy consumed by owner	50%
Share sold to utility	50%
Compound gain of solar current	15.8 Pf/kWh
Compound gain of solar current based on working price assumption	11.1 Pf/kWh
Life expectancy of solar facilities	20–30/years
Annunity	8.02–6.505 %/year
Operating and maintenance cost	12 Pf/W/year
Solar energy costs	
1982	267 Pf/kWh
1990	122 Pf/kWh
2000	62 Pf/kWh
2010	42 Pf/kWh
2020	32 Pf/kWh
2050	26 Pf/kWh

Notes: Pf = Pfennig, 0.01 of a German Deutsche mark (1982 prices); TWh = Terawatt hour; DM = Deutsch Mark (1982 prices).

the buyback rates as compared to 1990. The same law prescribes rates of 75% for electricity from biogas plants and small hydro installations. The resulting rate increases (about Pf8/kWh) corresponds roughly to the average figure of the difference in social costs between conventional and wind or photovoltaic energy.[15]

In the case of wind energy this law has led to a massive expansion in private applications for building permits for wind energy turbines in the coastal areas of Germany, which have average wind speeds above 5m/second.

If other countries will follow this example, the only question left on the widespread introduction of renewable energy sources is how fast these should or need to reach a 50% share in the global supply of energy services, or when do we need to approach 100%?

Certainly renewable energy will be *the* resolution to the 'thermodynamic interlude' and not just a

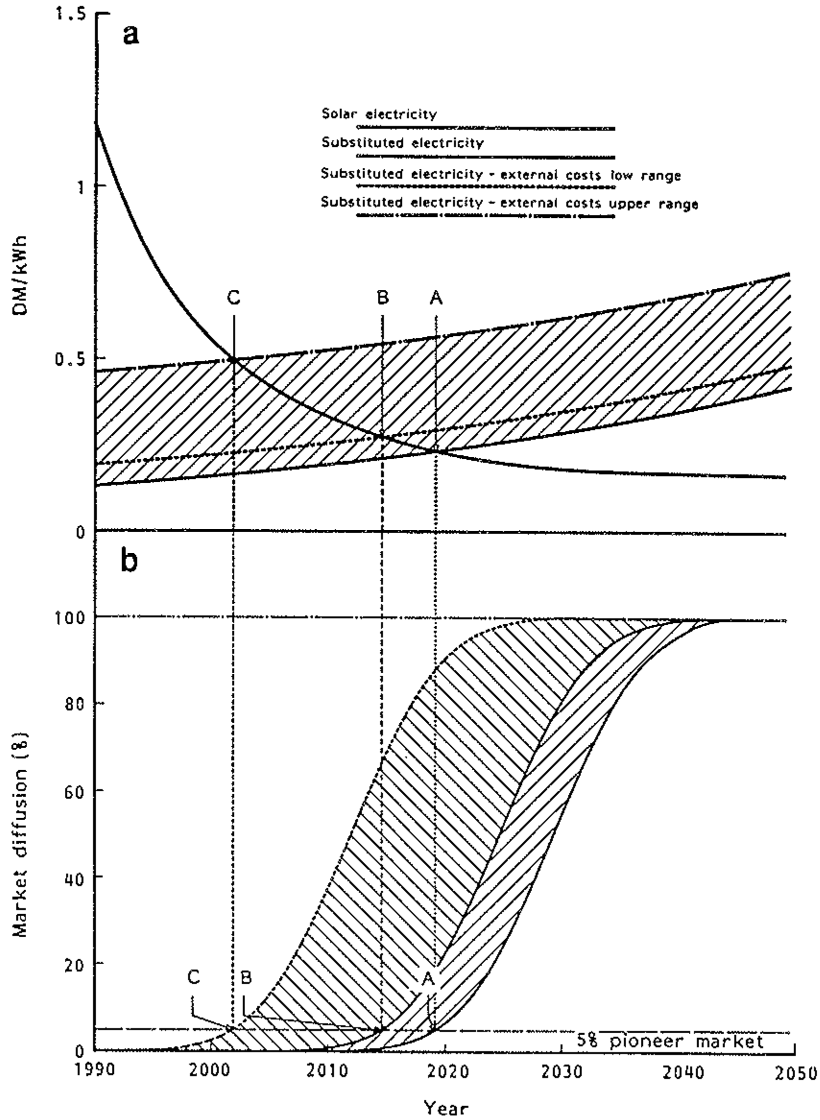

Figure 5. Influence of social costs on starting point of market penetration of decentralized photovoltaic systems and future market diffusion to year 2040.

Notes: (a) costs for photovoltaic electricity compared with costs for substituted conventional electricity; (b) market penetration of photovoltaics based on costs shown in (a).

deceitful signpost, a false promise on the inevitable road to disorder. Keeping the full costs of different energy sources in perspective this turns out to be considerably less costly than first glance evidence suggests.

[1]Tim Jackson, 'Renewable energy – great hope or false promise?', *Energy Policy*, Vol 1, No 1, January/February 1991, pp 2–7.
[2]Bent Søerensen, 'Renewable energy – a technical overview', *Energy Policy*, Vol 19, No 4, May 1991, pp 386–391.
[3]World Bank, ed, *World Development Report 1990*, Oxford University Press, New York, USA, 1990.
[4]According to neo-classical economic theory internal and external costs add up to social costs. Because the neo-classical definition of external costs again excludes certain cost elements of the production process handed on to third parties, Kapp (K. William Kapp, *The Social Costs of Private Enterprise*, Harvard University Press, Cambridge, MA, USA, 1950) criticizes this definition as being to narrow for analytical purposes. He suggests using the term 'social costs' to cover all cost elements of production and consumption processes handed on to third parties. As discussed in detail by the author in his original publication on this subject (Olav Hohmeyer, *Social Costs of Energy Consumption*, Springer-Verlag, Berlin, Heidelber, New York, 1988), the term 'social costs' will be used in this paper according to Kapp's definition.
[5]Hohmeyer, *Ibid.*
[6]Like the extensive US study by R.L. Ottinger *et al*, *Environmental Costs of Electricity*, Oceana Publications, New York, London, Rome 1990; or F. Barbir, T.N. Veziroglu and H.J. Plass, 'Environmental damage due to fossil fuel use', *International Journal for Hydrogen Energy*, Vol 15, No 10, 1990, pp 739–749.

[7]Two collections of papers on the subject should be pointed out besides the publications already mentioned: the special issue on 'Social and Private Costs of Alternative Energy Technologies', *Contemporary Policy Issues*, Vol VIII, No 3, 1990, containing about 30 papers on the subject; and, second, a report on a German-USA workshop on the subject '*External Environmental Costs of Electric Power Production*' O. Hohmeyer and R.L. Ottinger, eds, Springer-Verlag, Berlin, Heidelberg, New York, 1991, containing about 20 papers on the topic.
[8]See Olav Hohmeyer, 'Latest results of the international discussion on the social costs of energy – how does wind compare today?', *Proceedings of the 'European Community Wind Energy Conference'* Madrid, Spain, 10–14 September 1990, H.S. Stephens and Associates, Bedford, 1990, pp 718–724; and Hohmeyer, *op cit*, Ref 4.
[9]These include: the psycho-social costs of serious illness or deaths as well as the costs to the health care system; the environmental effects of the production of intermediate goods for investments in energy systems and the operation of these systems; the environmental effects of all stages of fuel chains or fuel cycles (specifically in the case of nuclear energy); the full costs of man made climatic changes; the environmental and health costs of routine operation of nuclear power plants; hidden subsidies for energy systems; costs of an increased probability of wars due to: securing energy resources (eg the Gulf War); proliferation of nuclear weapons know how through the spread of 'civil' nuclear technology; and costs of the radioactive contamination of production equipment and dwellings after major nuclear accidents.
[10]Jonathan Koomey, 'Comparative analysis of monetary estimates of external costs associated with combustion of fossil fuels', New England Conference of Public Utilities Commissioners, ed, *Environmental Externalities Workshop – Papers Presented*, Portsmouth NH, USA, 1990.
[11]See eg Olav Hohmeyer, 'Least-cost planning und soziale kosten', Peter Hennicke, ed, *Least Cost Planning – Ein neues Konzept zur Regulierung, Planung and Optimierung der Energienutzung*, Springer-Verlag Berlin, Heidelberg, New York, 1991.
[12]For an extensive discussion of such approaches see: Olav Hohmeyer, 'Adaequate berücksichtigung der erschöpfbarkeit nicht erneuerbarer ressourcen', paper presented at the Seminar, *Identifizierung und Internalisierung externer Effekte der Energieversorgung*, Freiburg, Germany, 19 April 1991.
[13]Hohmeyer, *op cit*, Ref 5.
[14]Source: Olav Hohmeyer, 'Social costs of electricity generation: wind and photovoltaic versus fossil and nuclear', *Contemporary Policy Issues*, Vol VIII, No 3, July 1990, pp 255–282.
[15]Hohmeyer, *op cit*, Ref 4, Table 1.

Secondary benefits of reduced fossil fuel combustion

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The paper was prepared for this seminar.

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Secondary benefits of reduced fossil fuel combustion*

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1. Introduction

This paper reports on several Norwegian studies of some *secondary benefits* of climate policies. The policies considered are the introduction of additional taxes on the use of fossil fuels, and the secondary benefits comprise local benefits of reduced consumption of fossil fuels. The studies show that these benefits can be substantial both measured against the GDP loss incurred as a consequence of the additional tax and measured in terms of ton carbon reduced. The studies, which all are based on the use of macroeconomic models coming from one of two "families" of models, are of an applied nature. Thus, emphasis is on presenting actual results more than on developing new theoretical ideas. The economic models are supplemented by post models calculating emissions to air of several polluting compounds (including carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides and particulate matter), and assessing the local benefits of reduced fossil fuel use and emissions to air. The models have been described in detail elsewhere and only a brief sketch will be provided in this paper.

The macroeconomic cost of restricting future CO_2 emissions from fossil fuel combustion have been studied intensively, both within a global and a national perspective. Edmonds and Reilly (1983a,b) pioneered in the field of global studies, followed up by Barns et al. (1992). This work was further elaborated by, among others, Manne and Richels (1991) and Manne (1992), putting more emphasis on modelling economic behaviour. Rutherford (1992) in turn incorporated trade of emission quotas in the model framework.

Most of the national and state wide analyses carried out to date are based on long term general equilibrium models. Examples of non-global analyses are Jorgenson and Wilcoxen (1989), Centraal Planbureau (1989), Conrad and Schröeder (1990), Manne and Richels (1990), Hogan and Jorgenson (1991), Bergmann (1990), Proost and Van Regenmorter (1992) and Glomsrod et al. (1992). Others have a shorter time horizon and include non-equilibrium effects (for instance Bye et al., 1989). While most studies based on macroeconomic models have concentrated on CO_2 emissions from fossil fuel combustion, a few studies have also included other pollutants of a more local nature (Alfsen and Glomsrod, 1986, Bye et al., 1989). Recent surveys of works in the field of carbon control cost illustrated by means of applied general equilibrium models, are given in Hoeller et al. (1990, 1991) and Nordhaus (1991a). Also Wuebbles and Edmonds (1991) cites marginal and average costs of reducing CO_2emissions from several studies. Earlier Norwegian works are reviewed in Alfsen (1991, 1992).

Unfortunately, at present it is extremely difficult to quantify the benefits of a slow down in climate change stemming from a reduction in carbon emissions (although see Nordhaus 1991b,c for pioneering efforts in this direction). In part this is due to the considerable time gap that exists between the introduction of carbon control measures and the (very uncertain) climate effects.

However, since more local air pollution problems are also associated with fossil fuel combustion, there are not only immediate costs, but also contemporary gains associated with CO_2 control policies. These secondary gains from a carbon control policy are in addition to the uncertain future benefits of slowing man-made climate change. Thus, limiting fossil fuel combustion will reduce emissions of local and regional air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO) and particulate matter, in addition to restricting carbon emissions in the form of CO_2.

These so called *secondary benefits of climate policies* are the main focus of this paper and results from a number of Norwegian model excersises are reported. The climate control policies considered consist of the introduction of additional taxes on fossil fuels, either reflecting the carbon content of the fuels or determined otherwise. The policies are either assumed introduced unilaterally in Norway or as part of an international climate treaty. Space limitation prevents a detailed presentation of the macroeconomic models employed or the underlying methodologies used for assessing the marginal local benefits of a reduction in fossil fuel use. Fortunately, most of these issues have been covered in other reports and papers on the reference list. The idea of this paper is rather to illustrate that assumptions on type of climate policy (unilaterally enforced or multilateral treaty), different "closure rules" of the models, different tax levels, etc. all lead to a rather large variation in the economic loss associated with a given reduction in carbon emissions. At the same time we find a certain robustness to the conclusion that the secondary benefits of these policies are of a significant magnitude and should be taken into account when formulating climate policies. The overall approach is in the spirit of applied research, using model tools, data and assumptions routinely used by actual decision makers in Norway.

The rest of the paper is organised as follows. Section 2 briefly outlines the structure of the macroeconomic models employed in generating the baseline and the tax scenarios. Section 3 presents the basis for the estimation of the secondary benefits associated with reductions in fossil fuel use. The uncertainties of the estimates are discussed. Section 4 then presents in a condensed form the macroeconomic costs and the secondary benefits as calculated in a number of Norwegian studies. Section 4 summarises and concludes the paper.

2. Economic core model

The results presented below are based on various versions of two families of annual macroeconomic multisectoral models; the medium term model MODAG and the long term general equilibrium model MSG. MODAG is an input-output based model belonging to the Keynesian tradition of macro theory, with mark-up pricing rules and non-competitive labour markets where wage rates are determined by Phillips curve equations. The parameters are estimated from national account time series, while input-output coefficients are calibrated in the base year. MODAG has 28 production sectors, 40 commodities and 14 categories of private consumption. Total energy input by industry is a CES-aggregate of the volume in fixed prices of electricity and fuels. The aggregate energy demand is proportional to gross output by industry, while labour and materials are substitutes under short run cost minimisation. See Cappelen (1992) for a detailed exposition of the model structure.

MSG is an applied general equilibrium model with the same numbers of commodities and sectors as MODAG. A nested production technology is specified by Generalised Leontief (GL) cost functions with four input factors at the top level; capital (K), labour (L), energy (U) and other material inputs (M). At the bottom level, demand for energy is further divided into electricity (E) and fuels (F) according to a constant return CES production function. Prices are generally set equal to unit costs, and private consumption is determined from the supply side in the MSG model. No intertemporal behaviour of the households is modelled. Export and import shares for manufacturing goods are endogenised by adoption of the Armington hypothesis which assumes that domestic and foreign products are imperfect substitutes. Earlier versions operated with exogenous export and import shares. Various closure rules have been adopted in different studies treating the pairs of the capital stock, the balance of the current account, the wage level and the real rate of return as exogenous variables, respectively. For a more detailed description of the latest version of the MSG model, see Holmøy (1992).

All parameters of the MODAG and MSG models are empirically estimated based on data from the National Account and the Energy Account. A documentation of methodologies employed and results obtained are given in Bye and Frenger (1992) and Mysen (1991).

Emissions to air of altogether nine polluting compounds are calculated in a post model to the macroeconomic models. The emission from stationary and mobile combustion and non-energy related processes are forecasted at a sectoral level by the demand for fossil fuel (F) and material input, respectively. Time dependent emission coefficients are calibrated in the base year and adjusted for future years to take into account control measures already decided on. For instance, three way catalysts for cleaning of exhaust gases from private small cars will gradually have an effect on automobile emissions as the stock of private cars is renewed.

3. Estimating the secondary benefits of a reduction in use of fossil fuels

The secondary benefits considered covers the following issues:

- Damage to nature due to acidification damages of forests and fresh water lakes
- Damage to materials due to sulphur induced corrosion
- Damage to human health
- Road traffic related damages due to accidents, congestion, wear and tear of the roads and noise.

Only damage from Norwegian emissions is considered. The marginal damage of national emissions of SO_2 and NO_x on nature has been estimated from the economic value of timber and fish and supplemented by contingent valuation studies of the recreational value of forests and fishing opportunities. Damage to materials has been estimated on the basis of physical damage functions (corrosion rates as a function of sulphur concentration in the atmosphere), the economic lifetime of various materials and the cost of maintenance. Damage to health from excessive SO_2, NO_x, CO and particulate matter concentrations are estimated on the basis of epidemiological studies of the effect of sulphur and particulate matter on morbidity and mortality in the United States. Assuming that the WHO-standards for other air pollutants reflect the same marginal damage as SO_2 at the recommended standard, and using expert assessment of the value of bringing one person from above the recommended limit to below that level, marginal benefits of reducing emissions of SO_2, NO_x, CO and particular matter are obtained. Finally, damage estimates associated with road traffic are based on various Norwegian studies.

Table I defines the parameters and reports the result (best estimates) together with a subjective assessment of the range of uncertainty for each parameter. It should be noted that are under way in refining and correcting the estimates in the table. The table only represents preliminary data which may be changed, perhaps radically, sometimes in the future.

Table II. Model parameters. Marginal environmental and traffic costs in thousand 1990-NOK per ton emission or fuel (b_j^i). Share of emissions causing health damage in per cent (a_j)

Type of costs		Para-meter	Low	Medium	High
Acidification of water	$b_1 \cdot \Delta (SO_2 + NO_x)$	b_1	0.11	0.19	0.31
Acidification of forests	$b_2 \cdot \Delta(SO_2 + NO_x)$	b_2	0.41	0.49	0.51
Health damage from SO_2	$b_3^j \cdot (a_m^j \Delta M_j + a_s^j \Delta S_j)$	b_3^{SO2}	59	155	259
		a_m^{SO2}	9	18	27
		a_s^{SO2}	3	7	11
Health damage from NO_x		b_3^{NOx}	194	555	1 070
		a_m^{NOx}	8	18	28
		a_s^{NOx}	3	6	10
Health damage from CO		b_3^{CO}	0.06	0.1	0.31
		a_m^{CO}	9	20	31
		a_s^{CO}	5	14	23
Health damage from particulates		b_3^{Prt}	194	555	1 070
		a_m^{Prt}	6	7	8
		a_s^{Prt}	8	17	26
Corrosion	$b_4 \cdot \Delta SO_2$	b_4	0	4.2	8.4
Traffic accidents	$b_i \cdot \Delta$(petrol+ diesel)	b_5	0.66	1.53	4.37
Congestion		b_6	0	1.64	3.28
Damage to roads		b_7	0	2.05	4.09
Noise		b_8	0.44	0.76	1.08

Marginal health damage takes into account that only a fraction of emissions from mobile (M) and stationary (S) combustion takes place in densely populated areas where health damage is most likely to occur. Also the amount of traffic work carried out is assumed to be proportional to the amount of petrol and auto diesel consumed. Further documentation of the data sources and the methodology employed in deriving these estimates is provided in Brendemoen et al. (1992).

4. Results

The general strategy used in calculating economic costs and benefits of an additional taxation of fossil fuel, is to develop a reference scenario usually on the general assumption of business as usual. Scenarios are then developed from various tax levels, assumptions about the scope of the tax policy (national or international), and constraints such as the future level of the current account, world market prices on oil and gas, alternative technologies in power production, etc. Of course, the effect of the tax policy will vary considerably with the assumptions made and also to some extent with the model employed, a flexible long term model or the more stiff medium term model. Below we report results from some 10 Norwegian studies.

Table II. Summary of results from some Norwegian studies of additional taxes on fossil fuel use

No.	Loss in GDP Billion NOK	Loss in GDP US$/tC	CO_2 reductions ktC	Year	Model
1	0.01	2	818	2000	MODAG
2	27	177	25,425	2010	MSG-TAX
3	14	795	2,937	2000	MSG-TAX
4	15	897	2,727	2000	MODAG
5	126	1,974	10,664	2025	MSG-5
6	34	2,757	2,061	2030	MSG-5
7	12	3,634	555	2030	MSG-5
8	15	5,974	405	2030	MSG-4
9	74	8,219	1,500	2000	MODAG
10	37	37,672	164	2000	MODAG

The table reports on absolute GDP loss in the final year relative to the relevant reference scenario, and also measured relative to the amount of carbon reduced. The studies are in the table ordered in ascending order of GDP loss per ton of carbon reduced. The absolute amount of carbon reduced is reported in the fourth column, while the last two columns inform on the time horizon of the respective studies and the model employed.

Figure 1.

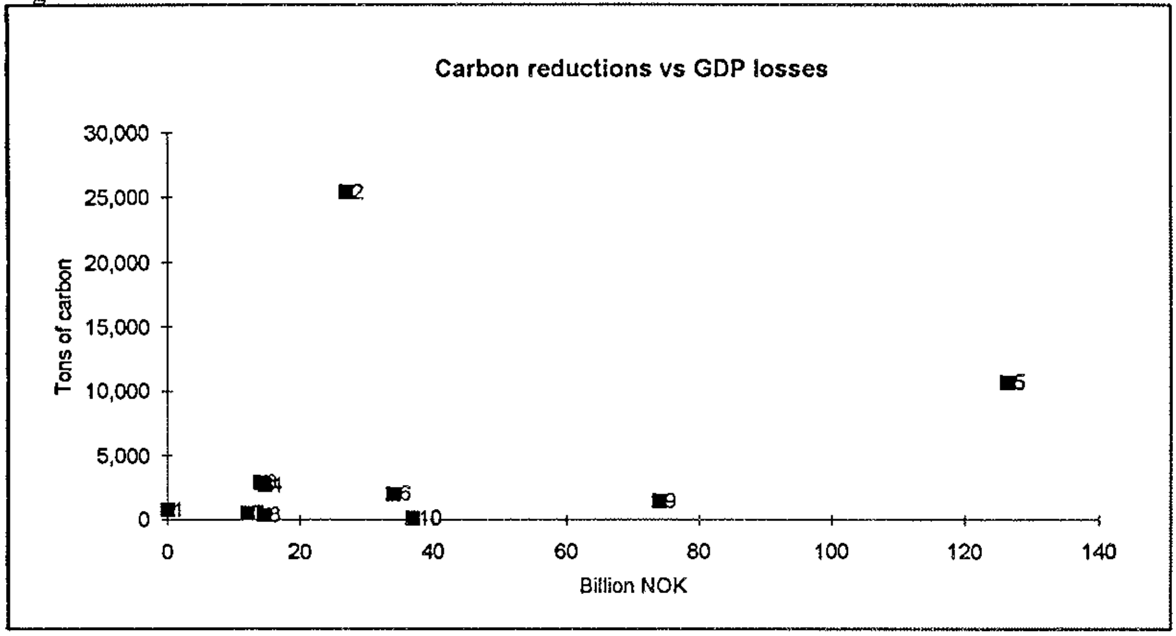


Figure 1 shows the carbon vs. GDP reductions in the tax scenarios relative to the reference path in the end year of each study. The numbers of the data points refer to the list of studies in table II. Except for study no. 2 the figure indicates an increase in cost, measured by the GDP loss, with increasing emission reductions. Two outliers are identified, namely study no. 2 with a large reduction in carbon emissions relative to the GDP loss, and study no. 5 that shows a large absolute GDP loss for a comparably small reduction in carbon emissions. In study no.2 the national tax rate was endogenously determined by requiring national stabilisation of CO_2-emissions after year 2000. Study no. 5 is based on an assumption of an international treaty with a high tax ($850/tC) introduced in all industrialised countries. A strong reaction on the world price of crude oil reduced the Norwegian income from oil and gas production considerably.

Figure 2.

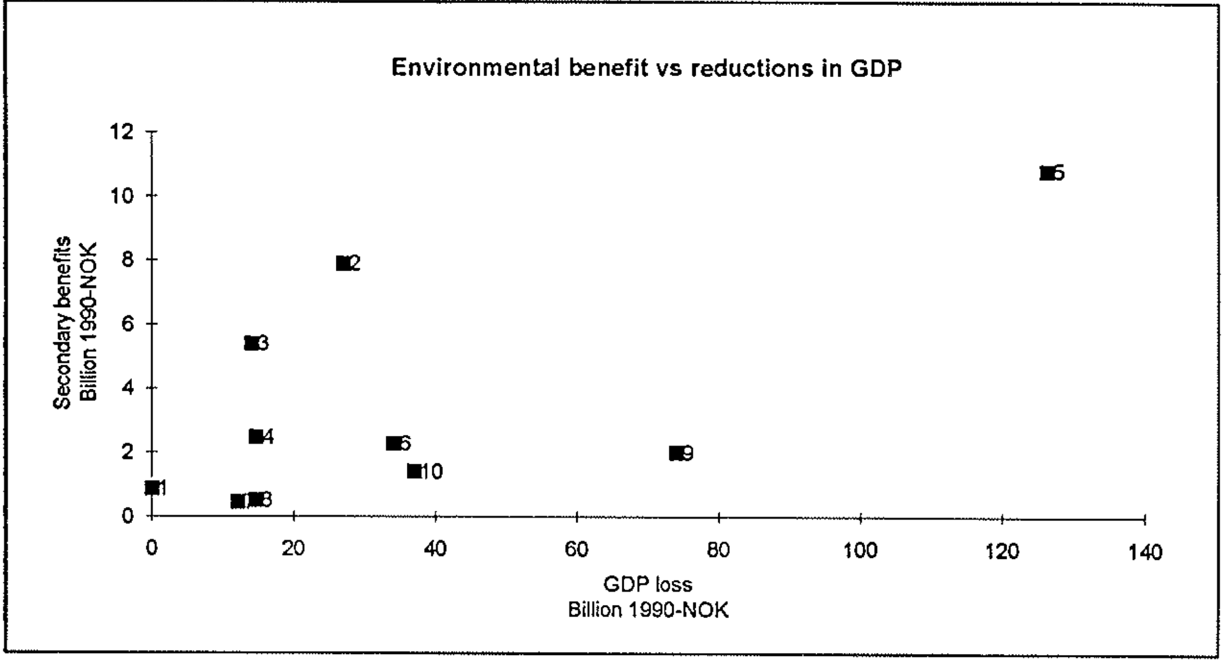


Figure 2 depicts the calculated secondary benefits vs. GDP losses in the various studies. Per unit of GDP loss, studies no. 1-3 show the largest secondary benefits, while studies no. 7-10 are at the lower boundary.

Figure 3.

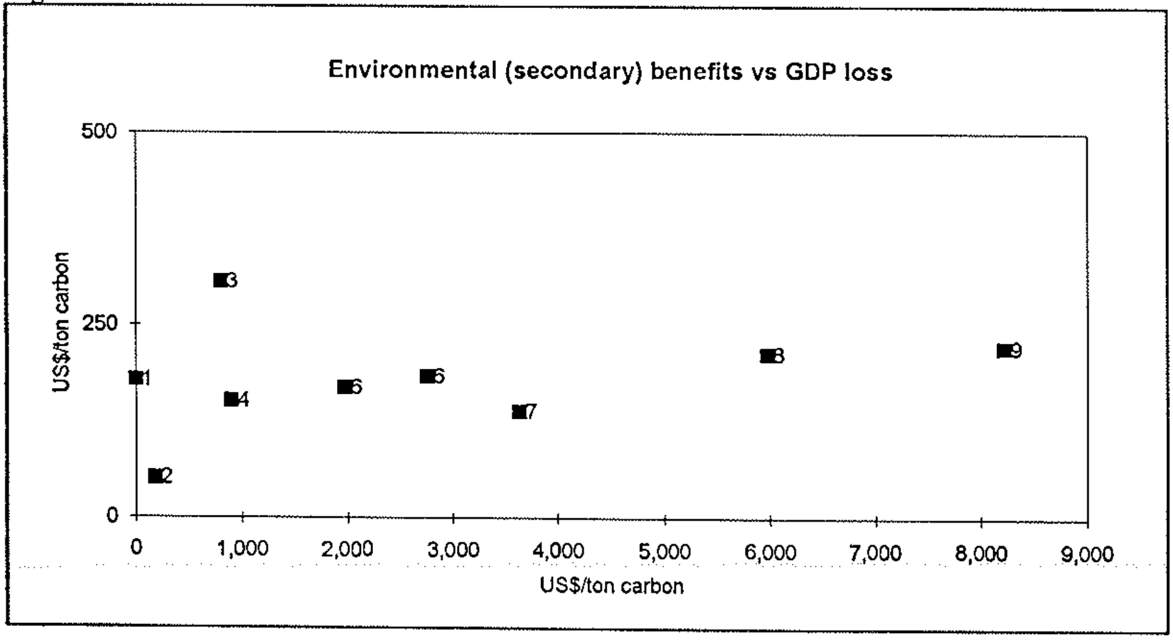
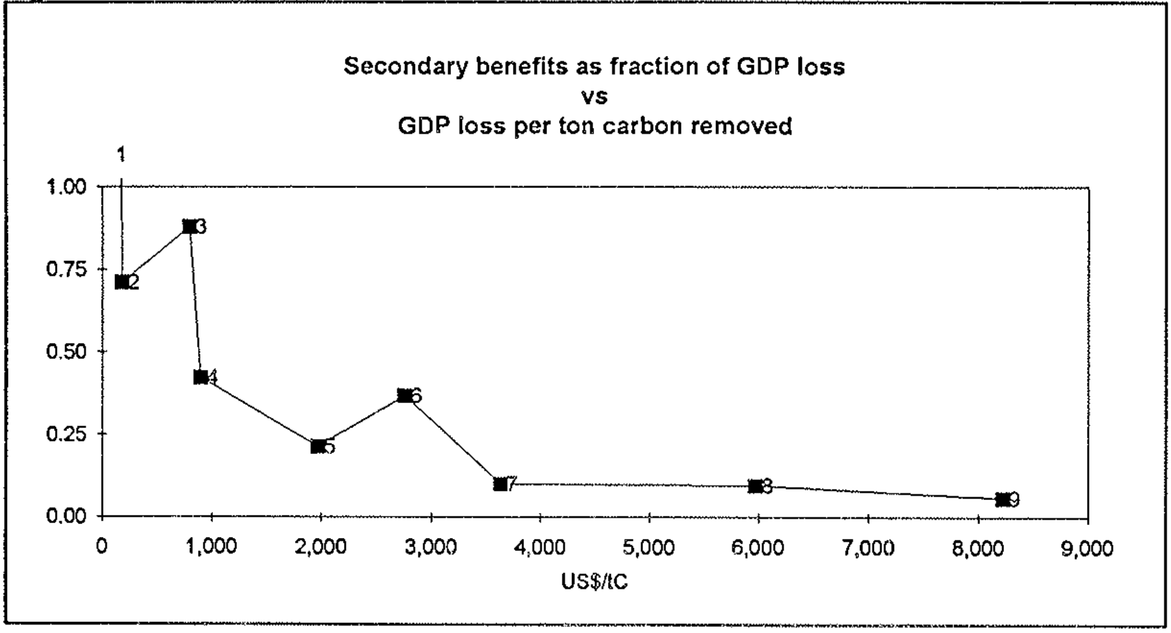


Figure 3 also shows secondary benefits exclusive of traffic related effects vs. GDP losses, but now measured per unit of carbon removed. Thus, the variation along the horizontal axis shows the GDP loss associated with the removal of a ton of carbon. As can be seen the efficiency varies considerably among the studies. Along the vertical axis the purely environmental (e.g. non-traffic related) secondary benefits per ton of carbon removed are depicted. This shows a concentration around a level close to 200 $/tC, reflecting the constant marginal benefits of reduced use of fossil fuels assumed in our model. Nevertheless, some variation around this level is apparent, in particular study no. 3 is somewhat above and study no. 2 somewhat below this level.

Figure 4



Total (e.g. environmental + traffic related) secondary benefits vary considerably when measured as fraction of GDP loss. Still, most of the studies indicate secondary benefits of the order of 10 per cent or more of the GDP loss. Considering that only a few components of benefits are included in the estimates included here (e.g. the primary benefit of the climate policy, non-use values of health benefits, etc. are left out), it is reasonable to assert that the secondary benefits are substantial.

The uncertainties associated with the above results are substantial. Besides the inherent uncertainty in economic modelling, we see that model closure and assumptions on for instance the oil market substantially influences calculated GDP loss due to a carbon tax. The benefit estimates are also highly uncertain at present, but perhaps not very much more uncertain than often cited results on GDP loss due to climate policies.

5. Conclusions

In applied economic models the effects of environmental taxes usually appear as reduced growth in macroeconomic indicators such as GDP and private consumption. When environmental measures such as a carbon tax nevertheless is contemplated as a response to the threat of climate change, it is due to a belief that the benefits of such a measure more than compensate the costs. However, the benefits associated with reduced emission of carbon dioxide and other greenhouse gases are difficult to quantify. It might be easier to put some tentative figures on so called secondary benefits of greenhouse gas control. These benefits accrue due to the fact that carbon control also will reduce emissions of other pollutants associated with combustion of fossil fuels, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter. For some reason, the secondary benefits are usually left out in assessments of carbon control costs.

In this paper we have presented some results from Norwegian studies of taxes aimed at reducing the emissions of the greenhouse gas CO_2. Particular emphasis has been put on calculations of so called secondary benefits of these taxes. The benefits were calculated on the basis of the methodology exposed in Alfsen and Glomsrød (1992), and are, of course, highly uncertain. Monte Carlo simulations were used in order to analyse some of the consequences of the parameter uncertainty underlying the benefit calculations.

The estimated benefits of reducing local pollution of SO_2, NO_x, CO and particulate matter seem to go some way toward mitigating the economic costs often associated with environmental control policies. A recent study carried out by Pearce (1992) for the UK also concludes that the secondary benefits of carbon control are substantial.

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External effects in the utilisation of renewable energy

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The paper was presented at the seminar by Poul Erik Morthorst.

Discussion paper to seminar on

External Effects in the Utilisation of Renewable energy
16 September 1993

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Poul Erik Morthorst & Lotte Schleisner (Risø National Laboratory)

It is generally recognized that externalities from energy production can constitute an essential part of the total costs. If these external costs to society are not included in the market price, many energy investments may be based on the wrong assumptions.

The main objective of the Danish project on externalities is to identify and describe the externalities of relevance in relation to renewable energy technologies. If possible, these externalities should be quantified and monetized.

The project was started early 1993 and a large part of the first phase has been used on a survey of the existing literature on economic theory and methodology in relation to externalities. The project is initiated by the Danish Council for Renewable Energy and is to be finalized mid-1994.

The present paper is divided into five major parts:

- The general economics of externalities
- The Danish project
- Biomass energy
- Wind energy
- Concluding remarks

The first part aims to define the more theoretical aspects of the project. The second part describes the purpose of the Danish project *External effects in the Utilisation of Renewable Energy*. The two following sections deal with more exact findings on externalities in connection with renewable energy, which in this project is biomass and wind energy, compared with the substituted non-renewable energy sources.

The present paper should only be considered as a discussion paper. No attempts have been made to write a comprehensive paper on the subject of externalities, but rather to raise some points and questions of relevance to the project.

The general economics of externalities

The introduction of external effects or externalities into the economic theory started in the beginning of the twentieth century through the further development of welfare theory. Introduction of externalities as known today can foremost be ascribed to Pigou. In connection with the definition of externalities, Pigou defined the social net production and private net production, factors that are inseparable from external effects. The phrases are often respectively called the social and private costs.

There are several definitions of external effects:

> *The essence of the matter is that one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservice to other persons ... of such a sort that payment cannot be extracted from the benefited parties or compensation enforced on behalf of the injured parties.* (quoted from O'Brien & Presley, p. 114, originally from Pigou: The Welfare of Economics, 1920).

The utility and production functions can be used as basis for the definition of externalities:

> *An external effect exist whenever the utility function of an individual or the production function of a company includes variables under the control of someone else, and where the dependence is not effected via the market mechanism.* (Keiding, 1992, p. 9).

In general externalities can be either positive or negative. A number of external effects is not directly connected to environment (for instance externalities like infrastructure, education etc.). This project will mainly deal with externalities linked to the environment.

Evaluation of the external effects can be divided into two major parts. The first part is calculation of the physical quantities of SO_2, CO_2 etc. emitted from various energy production technologies. The second part is the monetization of the effects of the physical quantities.

Monetization makes it possible to achieve two purposes: To establish the real price of the good, and to make comparisons between different types of externalities, which otherwise may be difficult. Through establishing the real price of the good, actions can be taken to ensure that price via taxes and subsidies.

Monetization is in many respects difficult, because it involves qualitative valuations and uncertain data. In reality it will be impossible to quantify and monetize all existing externalities, and therefore the results often represent a minimum of the total externalities in connection with the given energy form.

Externalities are often divided into externalities due to absence or failure of markets, and externalities due to failure of prevailing property rights. In some cases the way of dealing with the external effects is called internalisation, for example by adjusting the price of a given energy production to cover the externalities caused by the production[1]. In other contexts the term internalisation is more strictly reserved for situations where new markets are established or property rights changed in order to limit the externalities.

Markets and prices

In the economic theory goods are defined in a very broad sense. Therefore pollution can be viewed as a good which render a negative utility to the owner. In connection with externalities one of the principal problems is, that there in general does not exist a market on

1 Which would typically be done through a tax on the energy production or via a subsidy to another kind of energy production (Pigouvian tax or subsidy).

which these special kinds of goods (ie. externalities as SO_2, mercury etc.) can be exchanged with money. In relation to the monetization the problem is, that there are no markets where equilibria between quantities and prices are determined. There might be several reasons for why markets do not exist. It may be impossible or too costly to establish a market, or no attempts have been made for some other reasons.

If it is feasible to exclude some from benefitting from a specific good, it will in general be possible to set a price on that good.

Several suggestions have been made on how to circumvent the problems of the missing market-equilibrium and thereby the missing prices. One solution have been to try to establish surrogate markets for the given external effects either as real markets or as proxy markets. Possible ways of establishing markets are by issuing marketable permits of pollution, or by expanding the property rights (the last suggestion closely follows the Coase theorem).

It will not be feasible to initiate markets in every area where there is pollution. For instance it seems impossible to extend the rights of property to the ozone layer. A broad range of problems in respect to externalities simply cannot be dealt with through markets. This, on the other hand, cannot be used as an excuse for not trying to handle the problem of externalities in the economy.

Collective goods

To a large extent external effects is linked with public goods (in some texts called collective goods). There exist several definitions of public goods, but the main characteristics is that the consumption of the (public) good of one person does not reduce the possibility of other agents in the society to consume the good.

Some typical examples of public goods are national parks and defence[2]. The two main characteristics of the public good are consequently the non-rivalry in consumption and the non-exclusion[3].

The marginal costs

Looking at the cost of a specific kind of pollution (i.e. emission of SO_2) it is normal to try to estimate - at least in theory - the marginal cost of the damage the pollution generates and the marginal cost of reducing the pollution. In a number of cases it is possible to estimate parts of the cost function with a varying degree of uncertainty.

With regard to the marginal costs of the damage of the pollution it is important to distinguish between the damage cost and the cost of regenerating society to its pre-pollution level. The marginal cost function may be quite different in the two cases. Generally it would be expected

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2 In the recent year a more elaborate theory of club goods has evolved, through this theory the number of pure public goods has decreased rapidly. A club good is characterised by the excludable benefits, ie. the possibility to exclude some agents from the good. In that respect for instance a highway could be seen as a club good - it is feasible to exclude some people from the highway and charge a fare on exit from the highway.

3 In some contents the non-divisibility of the good is emphasised.

that the regeneration cost would be lower than the damage cost, though examples of the opposite are possible.

From a strictly economic point of view the regeneration cost function would in general be the least complicated to estimate. Take, for instance, a river that have been polluted. The regeneration cost could involve an initial cleaning of the river, the river bank, and the flora and fauna connected to the river. Each of these actions involves the cost of human interaction/labour for which there would be a price (wages, equipment etc.). It is possible to add each of the costs, thereby constituting the total costs of regeneration[4]. In some cases it could - and sometimes with good reason - be argued that it is impossible to recreate a given environment to the previous condition. That kind of case is normally called irreversibility and constitute a major problem[5].

The Danish externality project

The use of renewable energy technologies is to be seen in a close relationship with the existing conventional energy system. Therefore, it is important in the project to identify not only the externalities connected to the use of renewable energy technologies, but also the externalities in relation to the part of the energy system that is substituted by renewable technologies. In the project two case studies are included:

- *A biomass case*, where a combined heat and power plant fueled by biomass substitutes a small-scale natural-gas based CHP plant.

- *A wind energy case*, where wind turbines substitute a coal-fired condensing plant (or a CHP plant operated in condensing mode).

Externalities can broadly be divided into two main categories: Environmental externalities and economic externalities. The first-mentioned includes emissions of pollutants, the related health effects on human beings and other impacts on the human welfare. The latter includes consequences for employment and trade, and the exploitation of scarce resources.

The two case studies will focus on the environmental externalities, described in more detail later in this paper. The economic externalities will be analysed in less detail. A range of theoretical problems and practical uncertainties are related to the conventional approach of calculating employment and trade effects, using partial employment and trade coefficients. If possible these problems will be avoided by applying an existing macroeconomic model for estimating employment and trade effect of increased utilization of renewable energy.

4 Another aspect is the cost involved in the future keeping of the river - a preventive cost - which would probably include cleaning at the site of the polluters of the rivers (ie. industry and consumers).

5 The extinction of species is clearly irreversible. But in relation to larger biotopes it can often be difficult to distinguish between the extermination of a single specific biotope or the universal extermination of the biotope. The first circumstance cannot be called an irreversible situation while the second clearly is irreversible. As long as one biotope remains, the situation can be viewed as a kind of Noah's ark - regeneration is possible even if it is very costly.

Several approaches exist for monetizing environmental externalities:

- *The damage function*, which relates the quantity of the pollution to the cost of the damage to society. A typical example is the destruction of trees due to acid rain, which implies a cost for the plantation owner.

- *The regeneration function*, which relates the quantity of the pollution to the cost of reestablishing nature to the pre-pollution level. The areas with acid-destroyed trees might be replanted with new trees.

- *The abatement function*, which relates the quantity of the pollution to the cost of removing the formation of the pollution, either by removing the source or by using abatement technologies. Sulphur dioxide might be removed from the exhaust gas, thus deminishing the acid rain.

The intention in this project is to pay special attention to the damage cost function. The level of the damage cost function will be estimated for the externalities of relevance to the two cases, that is for biomass vs. a natural gas CHP plant and for wind energy vs. a coal-fired condensing power plant. The calculation will be performed given the conditions of the energy system today, and for a future year, where abatement technologies could be introduced to a wide degree. Finally, a lower boundary of the damage cost function might be identified by the critical-load level for some of the externalities, i.e. emissions.

The regeneration costs will only be estimated if the damage cost is impossible to calculate, or as a supplement to this.

Denmark is applying a number of abatement technologies in the existing energy system. The cost of abatement will be calculated not only for the present system, but for a future application of abatement technologies taking into account the technological development.

The calculated results for the damage cost function will be compared to the calculated marginal abatement costs, indicating the magnitude of the economic gains by imposing the external cost to the producer of the externality. Figure 1 shows typical examples of the damage and abatement cost functions.

Due to the practical and theoretical problems involved in estimating the externalities it must normally be expected that the estimated monetized externalities will represent a minimum of the total externalities that exist for the given energy form.

Biomass energy

Biomass has been used for energy purposes in many countries and in some countries it constitutes the most important energy source. The focus on biomass as energy source has increased in recent years, e.g. due to its position as a neutral CO_2 emitter.

In Table 1 the development in biomass utilization as an energy source in Denmark is illustrated. Not until recently biomass has become an important energy source in the planned development of the Danish energy system. Until 1972 the major biomass applications were utilisation of heat from incineration plants for district heating purposes and wood and wood chips for domestic heating purposes. However, since 1972 the use of biomass energy from wood, wood chip, biogas and straw has increased significantly.

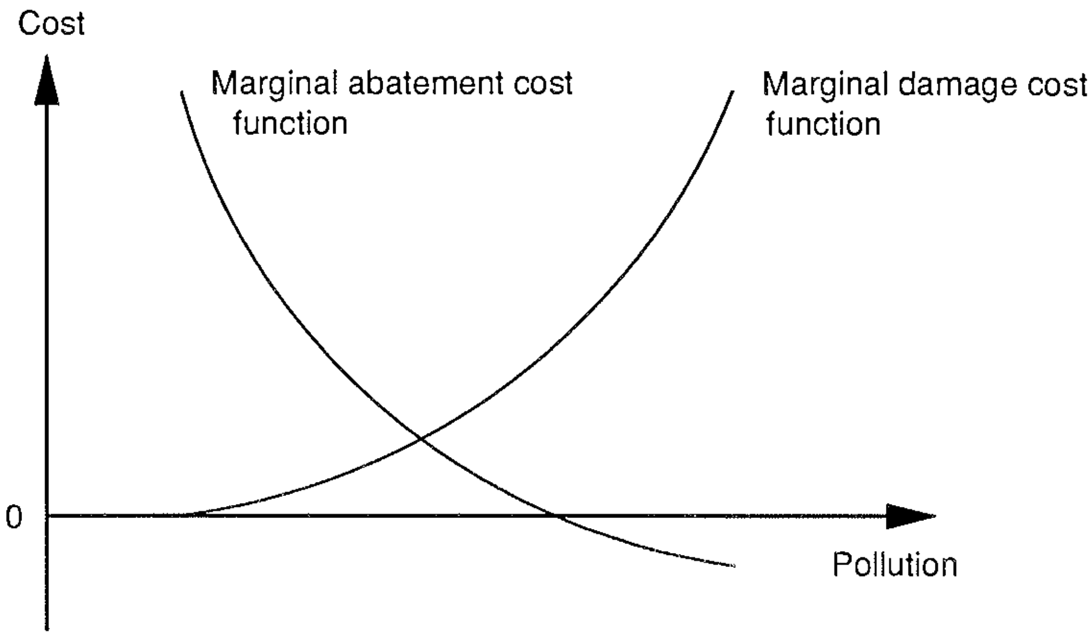

Figure 1. Cost functions for externalities.

Table 1. Development in utilization of biomass for energy purposes in Denmark, in PJ (ref. 7). The figures for total energy use are corrected for climate.

Source	Year		% of total energy use 1992
	1972	1992	
Waste (PJ)	8.4	17.3	2.1
Wood and wood chip (PJ)	4.9	17.7	2.1
Straw (PJ)	0.7	13.8	1.7
Biogas (PJ)	0.1	1.5	0.2
Total biomass (PJ)	14.3	59.8	7.3
Total energy use in Denmark (PJ)	824	823	

To obtain a full picture of externalities, the study includes externalities due to as well production, transportation as combustion. This is outlined in Table 2.

Table 2. The analyzed energy sources and processes in the biomass case.

Process step	Energy source			
	Grain	Willow	Wood chips	Natural gas
Production	x	x		x
Transportation			x	x
Combustion			x	x

The production process for grain and willow is described in detail, as the only energy crops analyzed. Externalities of the production of wood chips are not included, because wood chips are a waste product from foresting. Externalities in the production of natural gas will be analysed.

The transportation step will be included for the natural gas network and for wood chips.

For the combustion process a comparison between natural gas and wood chip will be carried out assuming that wood chips are representative for the biomass sources.

Table 3 shows in detail the comparison of the environmental effects between grain and willow cultivation.

Willow cultivation compared to grain cultivation increase species diversity among flora as well as fauna. When mud or waste water is used in the willow forest several small animals are affected. These animals accumulate heavy metal in smaller quantities, but only when birds of prey eat these animals they accumulate heavy metals exceeding critical loads. Surveys show that species diversity for fauna is similar in mud/waste water fertilized forests and forests fertilized by artificial fertilizers.

In general spraying with pesticides is lower in cultivated willow forests. Spraying with fertilizers is carried out every year in grain fields but only every 3-4 years in willow forests. Spraying against fungi has not any effect and spraying against infestant has not until now been necessary in willow forests.

A central question for the promotion of energy forests is the balance sheet for denitrification. As willows are to be cultivated in wet areas, the denitrification increases due to anaerobe conditions in the soil. If furthermore the willows are grown with supply of fertilizers, high amounts of N_2O are produced, because various microorganisms will use nitrate as oxygen source instead of using O_2. This is the case when artificial fertilizers are used as well as when manure is used. The N_2O is a greenhouse gas as CO_2 but with a much higher global warming potential.

Biomass as a renewable energy source has several advantages in a sustainable energy system. It has no emission of CO_2 to the atmosphere if crops are grown continuously. The crops assimilate exactly the same amount of carbondioxide as it emits when it is used for energy purposes. However, biomass has other emissions and environmental problems, as shown in

Table 3. A comparison of environmental effects of grain and willow cultivation (ref. 8, 9 and 10).

Environmental effects	Grain cultivation	Willow cultivation
Effect on flora	Mono culture	Species diversity between the cultivated plants is increased compared to cultivation of grain
Effect on fauna		Slightly better than grain cultivation (increased number of insects and birds)
Use of pesticides	Weed-, fungi- and insect-abatement each year	Weed abatement each 3-4 years
Nitrate percolation	Bare soil every year	- High water content in the soil - Pre-fertilized - Green all the year - Bare soil each 25th year
Denitrification (N_2O-emission)	Fertilized once a year	- Must be cultivated on wet soils - Big roots - Fertilized regularly - Mud/waste water can be used as fertilizers
Fertilization:		
Artificial	- Increased nitrate in the environment - Increased energy use	- Should not be used
Manure	- Utilization of natural nitrate source - Increased denitrification	- Natural nitrate source - Very high denitrification due to ammonia
Mud/waste water	- Assimilation of heavy metals	- Utilization of waste - Disposal of heavy metals - Utilization of natural nitrate source - Heavy metals diminish denitrification - High denitrification - Smell problems - 100% loss of mercury at combustion
Use of water resources	No demand for special soil and water conditions	Demand of much water and clay soil with good water-retaining capacity

Table 4. The table shows externalities from wood chip in comparison with natural gas used as fuels in a combined heat and power plant (CHP). The comparison only refer to the combustion process. The total level of emissions depends strongly on how the biomass is produced, transported and combusted.

Table 4. Environmental effects of wood chip in comparison with natural gas used as fuels in a decentralised combined heat and power plant. NO_x and N_2O figures are from combusting of straw as no figures for wood chip are available (ref. 12, 13, 14 and 15).

	Natural gas	Wood chip
CO_2	56.9 kg/GJ	CO_2 neutral
SO_2	about 0	about 0
NO_x	150-240 g/GJ	about 130 g/GJ
N_2O	2 g/GJ	3 g/GJ
VOC	5.0 g (district heat)/GJ	0.6 g/GJ
Mercury	0	Mercury content will be emitted to the atmosphere
Ash and clinker	0	1-4% of fired dry matter (contains heavy metals)

Natural gas has emission of CO_2 while wood chip is CO_2 neutral, but looking at SO_2, NO_x, N_2O and VOC the difference is negligible. A serious problem with wood chip is related to heavy metals. If wood is grown without fertilizers, problems with ash and clinker are reduced. But if wood is grown with fertilizers or dry matter from waste water treatment plants, problems with heavy metals will arise. Hence the external effects of the total balance sheet depend on as well the production process, the combustion technology and the waste treatment.

Wind energy

Wind energy is an energy source, which has increased considerably in Denmark through the last 10 years. Denmark is today internationally leading in the area of wind power. The growing application of wind energy is especially due to environmental considerations, as the production of electricity based on wind energy causes no emissions.

Figure 2 shows the development in the electricity production in Denmark based on wind energy. From the mid-70's until 1992 about 3300 wind turbines were established in Denmark with a total capacity of about 420 MW. For 1992 wind energy covered approximately 3% of the total electricity demand. The individual turbine capacity was in 1992 on average 200 kW against 20-30 kW in the late seventies. Today there exists commerciel wind turbines with a capacity of 500 kW, and capacities of 750 kW - 1 MW are expected during the next few years.

The government has made an agreement with the electric utilities of establishing additional 100 MW wind energy capacity in the energy system, and it is therefore expected that in late 1993 approximately 500 MW wind power are installed in total.

A potential for wind power production of about 8 TWh/year seems realistic, when conflicts with interests in other land uses, nature preservation, fishing etc. have been taken into consideration.

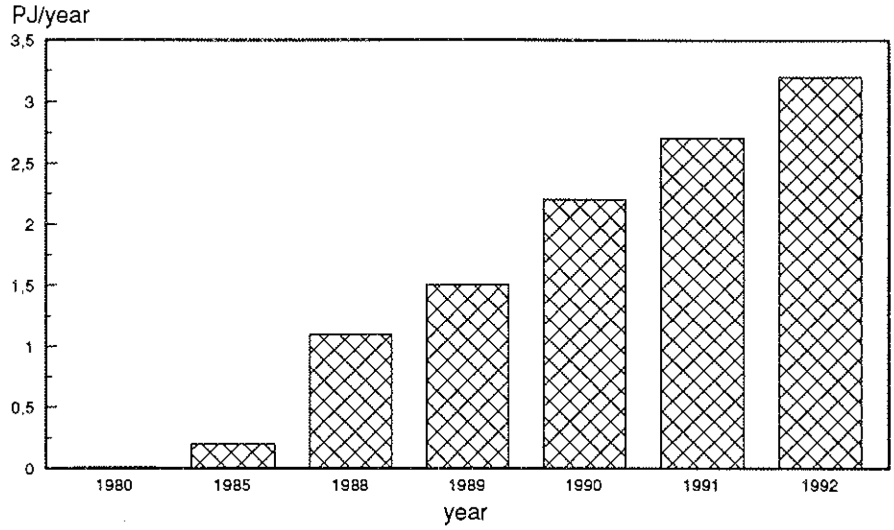

Figure 2. Electricity production based on wind power, PJ/year (ref. 16).

The development in wind power technology is expected to be focused on larger wind turbines for off-shore setting, as it seems increasingly more difficult to find areas for the wind turbines on land.

The development has resulted in decreasing costs per kWh produced. The price per kWh for turbines on good sites (characterized by a high average wind velocity) is today close to be competitive with the price on conventionel power plants.

The Committee for Wind Turbine Placements, set up by the Minister of Environment, ended their work in the spring of 1992, recommending that new extensions with wind turbines take place in groups or parks, which have been chosen with regard for landscape, preservation etc. Some municipalities have at the request of the Minister of Environment started a municipal planning of the expansion of wind power, where local interests are included.

The maximum potential for wind power in Denmark may be estimated by mapping the wind resources and estimating the production of energy with use of the most efficient wind turbines. In order to reach a realistic potential it is neccasary to balance the environmental advantages of using wind power for energy production against the environmental disadvantages.

The environmental externalities combined with wind power are

- confiscation of land areas
- visuel damage of the landscape
- interference with signals from radio and television
- noise
- influence of animal life
- lightreflections from the wings

It is possible to reduce some of these externalities, as for instance noise from the wind turbines. However, it is not possible to remove the noise totally, but to a level, where it is not considered as an externality anymore. The cost of reducing the above mentioned external effects and the costs of the damage each of the externalities causes, must be estimated and balanced against the environmental advantages of using wind power for energy production. The environmental advantages in using wind power may be calculated by estimating the emissions connected to electricity production on a conventionel coal fired plant. For the year 1992 the use of wind power for electricity production saved the environment for the pollution showed in Table 5. The table shows furthermore the emissions per kWh from a coal-fired plant.

Table 5. Pollution saved in 1992 by utilizing wind power for electricity production in Denmark and emission/kWh from a coal-fired plant (ref. 17).

	1992	emissions/kWh
SO_2	3,319 - 5,310 tons	5 - 8 g
NO_x	1,991 - 3,982 tons	3 - 6 g
CO_2	497,800 - 829,666 tons	750 - 1250 g
Dust	183 - 312 tons	0,275 - 0,470 g
Cinders/fly ash	26,549 - 46,461 tons	40 - 70 g

In addition to these emissions to the air a conventional coal fired plant causes other external effects:

External effects in soil:

- Leaking from coal storage
- Leaking from depots of ash and cinder

External noise effects:

- Noise in connection with transportation of coal, ash and cinder
- Noise from the plant

Other external effects:

- Heating of water (cooling water)

The cost of all the external effects from the coal fired plant must be estimated. Also as the costs of reducing the environmental effects (the abatement costs), and the damage costs of the reduced externalities must be estimated in order to compare wind power with conventional coal fired plants.

Concluding remarks

It is important that the decision maker is aware of the total costs involved in the development of the energy system. Decisions taken on insufficient cost estimates might lead to wrong investments, in a long-term perspective imposing additional costs to society. To include the existing external costs is certainly a step in the right direction.

Figure 3 illustrates how the expected results of the wind energy case might look like. Calculating the conventional costs will not be a main issue in the project, relying on the results achieved elsewhere. The external costs will be calculated per unit of energy production (where possible) and added on top of the conventional costs for wind turbines and coal-fired plants, at the present state of the energy system. Of course, a technological development is expected to take place in the future. Therefore, similarly the two technologies will be compared in a future year (say year 2010), taking into account a development with and without the use of abatement technologies at the coal-fired plants. Hopefully, this will show not only the magnitude of the today existing externalities, but indicate a possible development of the external costs in the future.

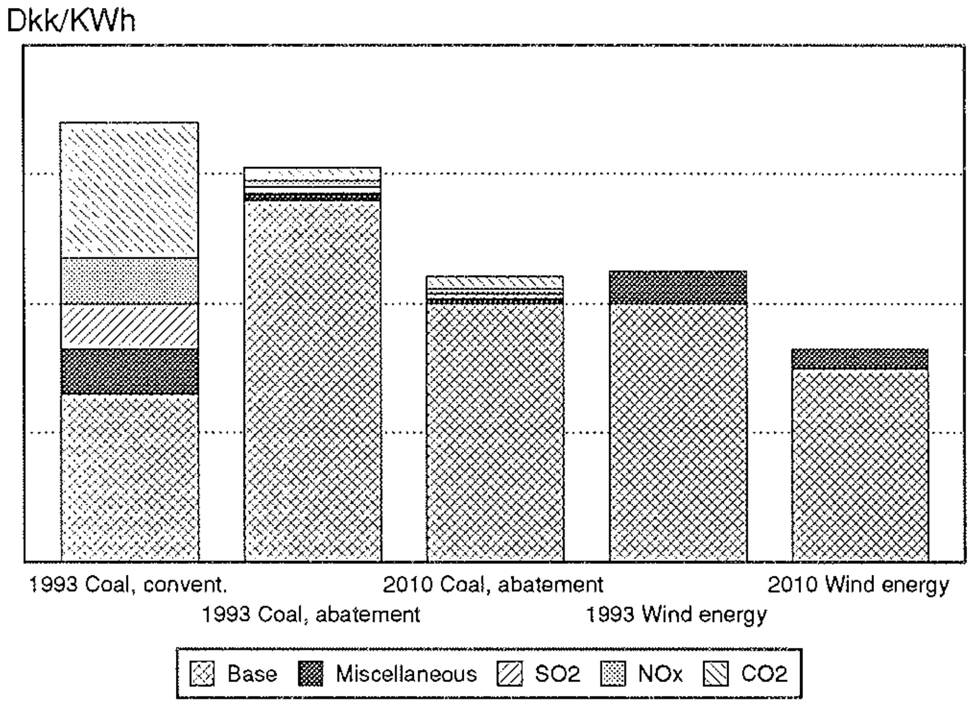

Figure 3. Illustration of the expected results of the wind energy case.

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Summary of the discussion concerning the seminar

The seminar included a discussion concerning methodology and goals of the Danish project. One line of discussion focused on a critical evaluation of the welfare theory as a basis for analyses of external effects (externalities). Other participants were contributing specific comments and proposals in relation to the project.

The main points of the discussion are summarized in the following.

General comments and recommendations to the project

It was generally found that the project is important and relevant. The energy sector is of central importance for the creation of a sustainable development, especially in relation to the man-made greenhouse effect. The choice of wind power and biomass as case studies were supported.

It was emphasized that the theoretical basis should be clearly presented and detailed arguments should be given for the chosen methodology. There is a widely varying uncertainty in the quantification of different types of damages. This should be clearly exposed, and the assumptions made should be transparent. It would probably be relevant to structure the damages in groups according to types and magnitude of uncertainty. In Norway, studies had first listed ideal objectives, and then in the next step compared these objectives with the practical possibilities.

Another important suggestion was that the project should be careful with the pure physical accounting. It was vital that the physical data should be estimated carefully. It served no purpose to make a meticulous monetization if the physical accounting was inadequate.

The possibility of using the contingent valuation method (questionnaires) was discussed. It was the general opinion, that contingent valuations should be avoided if possible.

In general it was found that the chosen scope and methodology of the project were relevant, and that the project as planned could contribute to new knowledge in the field.

A critique of the welfare theory

A strong critique of general welfare theory was stated by an economist participating the seminar.

It was suggested that the basis of the project was highly reliant on the framework of the welfare theory in economics. In consequence of this it was recommended that the concept of externalities was abandoned. The concept of external effect was an integrated part of the theory of welfare stemming from the neo-classical economic school. Because of the dependency of the preferences and utilities of individuals it was recommended that the whole approach to the problem was abandoned. There was made no concrete attempt from the critic to recommend an alternative approach.

It was put forward that the damage-function was founded on the theoretical preferences of individuals, but that the regeneration function was based on something different.

Responses to the critique

Several participants pointed out, that the strengths and weaknesses of welfare theory are well known, and that the concepts and methodologies of welfare theory and externalities have been improved and expanded since the original theories were published.

Some participants pointed out, that the goal of the project was not to use or develop new types of social welfare functions. The goal is less ambitious, and the project focuses in its first phase on developing relevant methodologies for describing externalities coming from different parts of the energy system. The project should not aspire to solve all the problems of economics.

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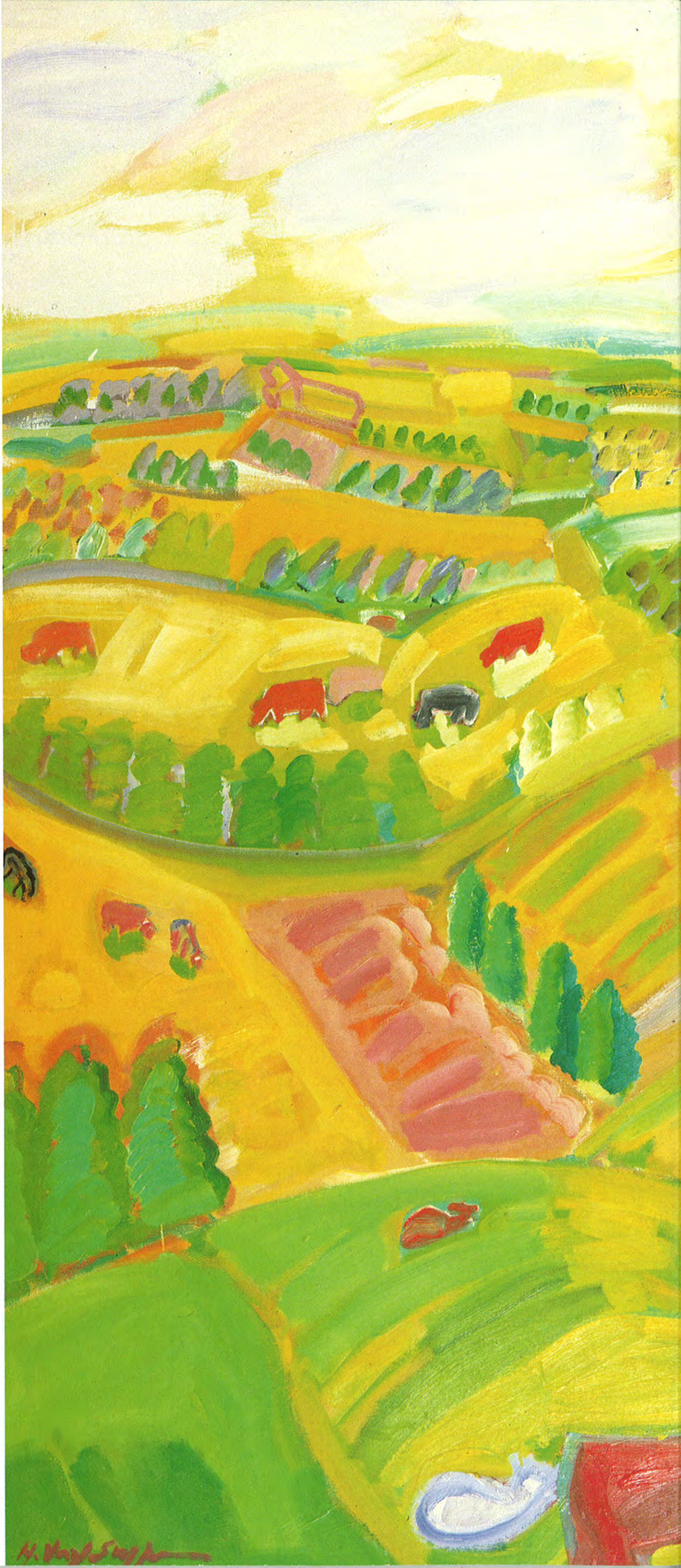

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